

Reentry into a Shotcreted, Underground Heading

by Michael Rispin

Whether in a mine or a tunnel, the concept of keeping all people working under supported ground is an essentially sacred one. Even with the most stable ground, the risk of a ground fall causing injury to persons or possessions is greatly mitigated once proper support measures are installed. This becomes even more critical as the quality of the ground diminishes.

Why Shotcrete for Underground Support?

The productivity of a mine has the same goals as the quest to complete a tunnel project—safely and on time. A key aspect to achieving this goal is to excavate and support the working face as quickly as possible, allowing reentry of people, equipment, and materials to start construction of the next advance in safety.

As with tunnels, the use of high-performance wet-mix shotcrete has increased in mines dramatically over the last few years, and year after year has seen a stepwise increase in shotcrete performance, particularly in the first few hours. Shotcrete early-age strength development clearly offers mining teams enormous advantages by allowing early, safe reentry to the face. In the hard rock tunneling field, modern shotcrete approaches do not cause delays in reentry, but allow a continuous construction cycle. Suitable, up-to-date shotcrete admixture and equipment technology is available to the underground community to permit early reentry.

Reentry

The reentry time really defines when work can resume in an advancing underground heading. Because shotcrete, like cast-in-place concrete, requires time to cure and develop strength (compressive, flexural, and bond), even when accelerated at the point of placement, its ability to support ground changes as it cures.

As the use of shotcrete becomes more widespread and underground companies evaluate shotcrete integration into the development cycle, the waiting time before reentering a shotcreted heading becomes of greater significance. This is particularly true in single heading development where rapid cycling carries great economic impact on the viability of the heading.

A number of considerations come into play

when evaluating an appropriate waiting time for reentry, including:

- Ground conditions;
- Shotcrete strengths specification;
- Applied thickness;
- Quality of application; and
- Curing conditions.

The need for development/production and safe ground control practices is affected dynamically by the above parameters, and all must be taken into consideration when establishing reentry practices. Due to a general lack of shotcrete design criteria, as well as a paucity of empirical criteria, mines have tended to be conservative when first establishing standards for reentry into shotcreted headings. Efforts are then made, as experienced curves and “zones of comfort” widen, to permit earlier reentry.

By comparison, the civil tunneling industry has a far greater database of experience and design criteria from which to draw and, as a result, has generally applied more liberal reentry practices. While absolute parallels cannot always be drawn, the mining industry stands to benefit by benchmarking civil practices where shotcrete is concerned.

Further, advancements in modern shotcrete technology have facilitated higher performance mixture designs, and the relative safety of reentry at earlier ages has increased substantially.

Reentry Criteria

The criteria for reentry into a shotcreted heading (or any otherwise supported underground opening for that matter) could be summed up as being when the conditions are such that any risk to human safety or equipment damage is at an acceptable level.

Accordingly, this gives rise to a discussion of the potential risks or dangers posed:

- Fall of ground through or with the shotcrete;
- Inability of shotcrete to support its own weight;
- Mechanical dislodge; and
- Blasting.

Different potential failure modes of shotcrete are illustrated in Fig. 1: To punch through shotcrete in a shearing manner, or to fail first in bond then in diagonal shear, a block of ground of sufficient size would have to detach completely from the surrounding rock mass such that its weight was being borne entirely by the new shotcrete (the “falling block” theory).

Given the level of confinement provided by the shotcrete and its developing bond strength, this is unlikely to occur, except possibly during shotcrete application or very immediately thereafter if dislodging was exacerbated by the application process. Consequently, falls of this nature are not likely to occur as a result of a gradual failure manifesting itself some time after (that is, beyond the reentry waiting period) application.

While occurring at a greater frequency, the falling of shotcrete due to its own weight (“pies”), or as a result of dislodging a substantial block during the application process, typically does not pose a danger to human safety as the operator is removed from the danger zone through proper positioning away from the mechanical application boom being used. Further, proper shotcrete mixture design, accelerator dosing, and application technique virtually eliminate this occurrence in day-to-day operations. Development of bond strength is such that if the pie does not fall within the first 20 min or so, it’s not likely to fail thereafter as a result of an inability to support its own weight.

Mechanical dislodge is an issue, and risks can be increased through inadvertent striking by a piece of equipment or by the mechanical/hydraulic action of drilling through the shotcrete. Here, control of drill water is most important to avoid washing out the green shotcrete in the immediate vicinity of the collarage. Again, development of bond strength within the first 60 min is such that only the most flagrant disturbances would cause the shotcrete to fail, and would likely be in such a locally affected area that the danger posed would be minimal. Notwithstanding this, adequate care should be taken to prevent contact from happening in the first place, as with all forms of ground support in newly excavated workings.

The risk posed by blasting is also minimal. Any local blasting event generating sufficient energy to dislodge curing shotcrete would typically require the area of excavation to be vacated anyway. Applied shotcrete, even including right up to the active face, has proven experientially to be remarkably resilient in standing up to the violent forces accompanying development blasting.

Recent Performance Enhancements

Confusion exists between shotcrete setting and early-age strength development. Setting of the shotcrete should be considered from 0 to 73 psi (0.5 MPa). This may occur between 6 min and 1 h depending on the dose and type of alkali-free accelerator used, and is measured with a Proctor penetrometer.

Early-age strength development should be considered as measurements being above 73 psi

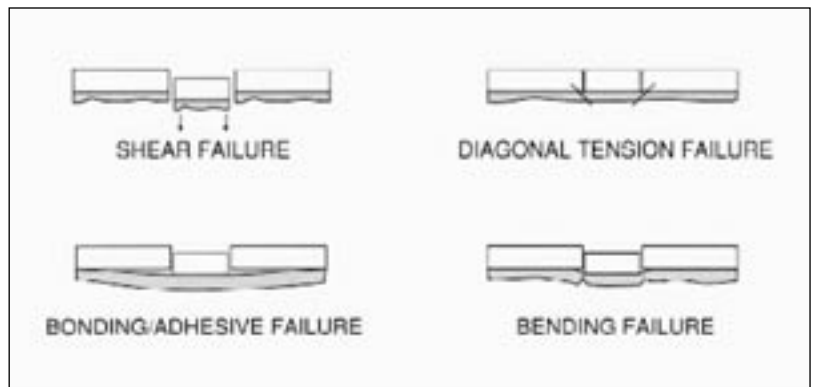


Fig. 1: Potential shotcrete failure modes

(0.5 MPa) and those recorded up to age 24 h. It is common practice to measure these strengths using the HILTI pullout test method.

Particularly in tunneling where the shotcrete lining will experience the greatest loading directly behind the excavation face (refer to Fig. 2), it is crucial that the strength development be continuous after the initial setting, and not remain dormant until age 6 to 10 h. In other words, traditional views of a “good” shotcrete purely based on fast, immediate setting characteristics are dangerous, as limited or no strength development afterwards may endanger the operatives at the tunnel face. With the increase in mechanized soft- and hard-rock excavation methods, production rates have increased. With increased excavation rates, shotcrete compressive strength development is also required to increase in step. This has been facilitated with the adoption of shotcrete with very low water-cement ratios (w/c) and the use of high-performance alkali-free accelerators.

It is vital in soft ground tunnels that the choice of alkali-free accelerators for shotcrete should be based on providing setting and strength development characteristics that remain in the early strength J_2 and J_3 classes defined by the Austrian Concrete Society Sprayed Concrete Guidelines (1999) in Fig. 3, particularly from age 2 to 6 h.

The demand for durable, permanent shotcrete structures has increased with the increased use of shotcrete as a ground support system. Evidence from Europe, particularly the UK and Scandinavian countries, has demonstrated shotcrete to have appropriate durability parameters, such as good sulphate resistance, low water permeability and continued strength development. Coupled with rigorous site inspection and quality control procedures, shotcrete can be used as a permanent support material with compressive strengths in excess of 5800 psi (40 MPa).

Mixture Design

The main mixture design criteria and means to establish high early and long-term shotcrete strengths are summarized as follows:

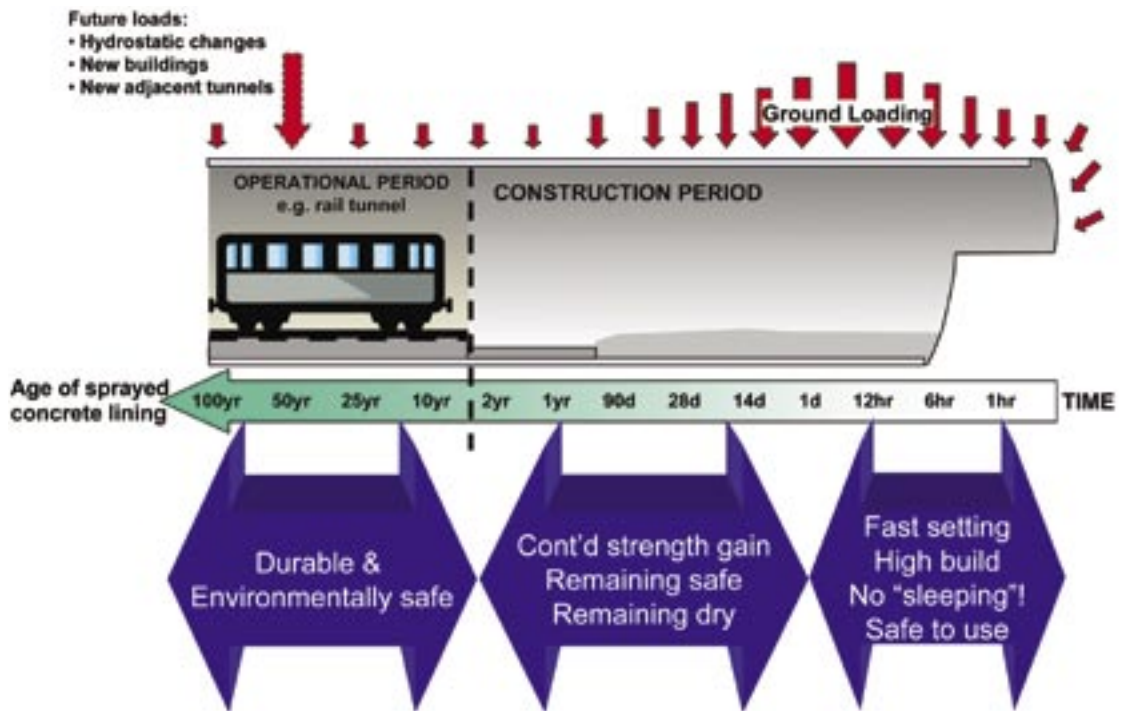


Fig. 2: Modern shotcrete requirements for tunnels

- A well-graded material suitable for the shotcrete application system in terms of pumpability, workability, rebound reduction, and good compaction. All aggregates should be checked for alkali-silica reaction. Maximum aggregate size should be no greater than 3/8 in. (10 mm).
- Adequate cementitious content, typically 670 to 840 lb/yd³ (400 to 500 kg/m³). The cement content should absolutely not be less than 590 lb/yd³ (350 kg/m³). The cement-accelerator reaction should be checked to define the best combination for site.
- Low, predefined w/c less than 0.45, achieved using water reducing agents/superplasticisers. Modern superplasticisers, referred to as “hyperplasticisers” can provide w/c between 0.35 and 0.4, while maintaining a slump of 8 in. (200 mm). This extremely low w/c allows for excellent early strengths and improved long-term strengths.
- Use of hydration control agents to extend working time and arrest the hydration process until such time as the shotcrete is being placed, where it is activated at the nozzle with the addition of the set accelerator.
- Use of alkali-free accelerators for high early strengths and less reduction in final strength compared to the base mixture, reduced rebound and dust, and most importantly, to provide safe working conditions.

Equipment

The application of shotcrete via poor equipment may ruin all the efforts made by composing a good

shotcrete mixture design and other actions taken to produce a high quality shotcrete. Only with a balanced system of reliable spray equipment, high-performance products, and competent service can the required quality and efficiency be achieved.

Reentry Practices

Mines—North America

In North American mines, the reentry times into working faces have varied to quite an extent. The norm in the past for reentry into a shotcreted heading has been in the 8 to 18 h range. Generally, today, the reentry time for standard shotcreted headings in most mines is 8 h. There has been a thrust to move that standard lower to 4 h and eventually to 2 h.

With the technology advancements of high early-strength shotcrete, 4-h reentry time is being used in North American mining today. This advancement has been achieved safely and economically on an ongoing basis.

The value that early reentry shotcrete brings to a mine from both the safety and economic standpoint will expand the use of shotcrete in North American mines.

Mines—International

Internationally, the use of fiber-reinforced wet shotcrete (FRWS) in mining has proliferated at a greater rate than in North America. As such, there are areas in the world where, as previously alluded to, less conservative reentry practices are in effect.

The Australian mining industry, with the application of over 130,000 yd³ (100,000 m³) of wet-mix shotcrete annually, has been a leader in the

practical and technical aspects of shotcrete in the underground mining environment. As such, it has been on the cutting edge of a number of developments in the technology; early reentry is an excellent example.

Junction Mine (St. Ives Gold, Australia)

The Junction Mine, characterized by high seismic activity, uses shotcrete as primary support, in a system that includes a subsequent installation of split sets and mesh. Robotic application of the friction bolts and mesh begins 2 h after shotcrete emplacement, with personnel reentry permitted after 4 h.

North Parkes Mine (Rio Tinto, Australia)

The second underground block caving operation at North Parkes Mine, known as Lift 2, used fiber-reinforced shotcrete in the development cycle from its inception in March 2001. During development, higher than predicted stress was encountered and small seismic events occurred. This resulted in a review of the performance requirements for the fiber-reinforced shotcrete with early reentry as an important objective. The implementation of early strength test methods to confirm an early unconfined compressive strength of down to 145 psi (1 MPa) has enabled the development crews to identify that this specification level is typically reached at 1 h.

Ridgeway Mine (Newcrest Mining, Australia)

This underground sublevel caving operation, similar to the aforementioned North Parkes Mine, began a concerted ground support program using shotcrete from its inception. In trials using a penetrometer, the mine can also typically obtain compressive strengths at 1 h of greater than 145 psi (1 MPa), allowing reentry of drilling jumbos after shotcrete application.

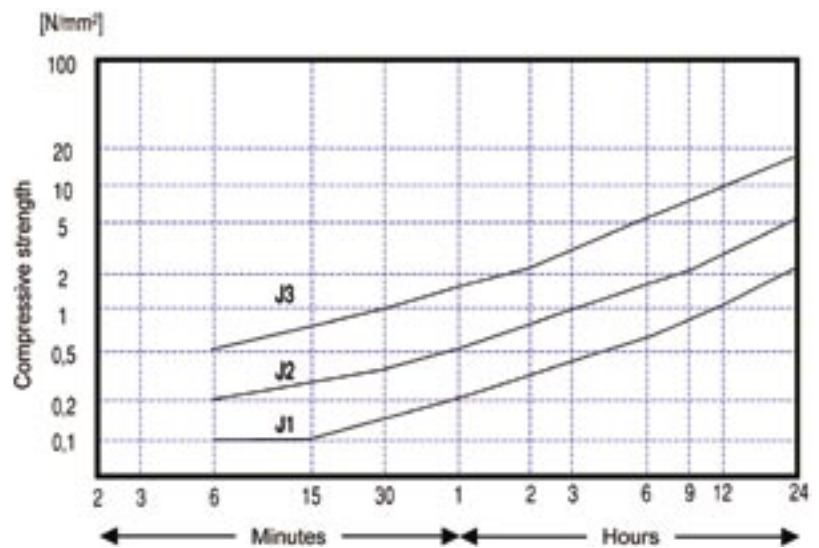
Jetcrete Australia (Mine Contracting Services)

Jetcrete, a renowned contractor performing shotcreting operations at many Australian underground mining operations, also follows a reentry criteria of 145 psi (1 MPa) compressive strength. The methods used to determine early strength have varied from physical assessment by experienced hand probing to today's preferred method of using a handheld penetrometer.

Depending on the mining operation and the mixture design employed, the required strength is typically achieved in 90 to 120 min. Jetcrete relies heavily on strict quality control measures regarding mixture design, dosing systems, nozzles, and state-of-the-art accelerators to obtain early reentry.

Civil Tunnels

As referred to previously, the experience curve with shotcrete in this industry segment is considerably greater. While no specific design criteria may be pointed to, as they are typically project dependent,



Sprayed Concrete Class	Application
J ₁	Sprayed concrete suitable for the placing of thin layers on a dry base without special load-bearing requirements to be met during the first hours after placing; it offers the advantages of low dust formation and rebound.
J ₂	Sprayed concrete that is required to be placed as quickly as possible in thick layers (including overhead). Additionally, sprayed concrete can be applied to water bearing ground, and sections of lining that are immediately adjacent to construction operations involving immediate stress and strain changes, such as new excavations or spiling. In normal tunnel conditions, J ₂ should not be exceeded.
J ₃	Sprayed concrete for support to highly friable rock or excessive ingress of water. Due to the high level of dust and rebound, this class should only be used in limited areas.

Fig. 3: Early-age shotcrete development (Austrian Concrete Society Sprayed Concrete Guidelines, 1999)

the observational method of engineering is typically applied, per this author's experience, on a day-to-day basis.

Some Scandinavian conventions accept that shotcrete is "safe" to work under once it has reached a compressive strength of 73 psi (0.5 MPa). In most cases, however, a 30 min waiting time prior to reentry appears to be industry accepted.

Conclusions

Modern underground civil and mining operations that employ shotcrete as a key component of ground support regularly permit reentry into shotcreted headings as early as 30 to 120 min.

Early-strength measurement methods, permitting identification of unconfined compressive strengths as low as 73 psi (0.5 MPa), are used as a benchmark to identify conditions under which reentry can safely and acceptably be permitted.

While North American tunnels and mines have and continue to adopt shotcrete as an efficient and cost effective tool in day-to-day operations, further gains from the perspective of improved development cycles, and the adoption of ever more rapid development techniques, can be realized. Benchmarking of existing practices elsewhere should lead to the adoption of more liberal, but acceptably safe, practices.

References

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