Shotcrete Applications at Northparkes E26 Mine

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Shotcrete was used extensively during construction of Northparkes E26 Underground Mine, Australia’s first block cave mine. Applications for the shotcrete included ground support, ground control, construction, safety, protection of equipment and remedial repairs. This article details the various uses for the 16,700 m³ (22,000 yd³) of shotcrete applied at Northparkes, the experiences gained during construction, and discusses whether the design expectations have been achieved.

Features of the block caving mining method used at Northparkes include high production rates from multiple drawpoints, hard blocky ore fractured along gypsum veins and loading/unloading of pillars from mining induced stresses. On the Extraction Level situated 480 m (1,600 ft.) below the surface, the drawpoints are subjected to high abrasion from the flow of ore, as well as impact from both secondary blasting and from the production Load-Haul-Dump units (LHDs).

Geology
The E26 orebody consists of a vertical cylinder of porphyry copper-gold mineralisation that is 200 m (660 ft.) in diameter extending down to 800 m (2,600 ft.) below the surface. The central core is dominated by bornite and lesser chalcoite enveloped by a chalcopyrite dominant zone and then a pyrite-magnetite zone.

Geotechnical
The E26 orebody and surrounding volcanics are generally strong rocks, with mean intact rock strengths of 110 MPa (16,000 psi) for the volcanics and 140 MPa (20,300 psi) for the intrusives. The rock mass is generally well jointed with some narrow NW trending faults and shear zones evident. The fracture system at E26 is dominated by the steeply dipping joint set and the flat dipping gypsum veining. The rock mass strength is reduced by the jointing and the gypsum veining.

Design Requirements
The rock mass strength and the structural intensity and orientation, along with the favorable geometry, all made the E26 deposit amenable to block caving. Once the rock mass was undercut by drilling and blasting a 45 m (147 ft.) high slice across the entire plan area of the orebody, caving propagated upwards to the surface. The underground mine was designed to produce 3.9 million tonnes (4.3 million tons) per annum.

However, the rock mass characteristics that made block caving an attractive low operating cost method also necessitated extensive ground support to ensure the longevity of the underground excavations. The blocky nature of the ground required early support to prevent loosening of blocks from subsequent development blasting (Figure 3). It was determined early in the mine design that an integrated rock mass support system was required that would both support the rock after excavation and reinforce the rock mass in order to withstand the mining induced stresses from the block caving sequence.

Steel fiber reinforced shotcrete (SFRS) was used as part of the mining cycle to supplement the rockbolt and mesh strap ground support.

The objectives of the ground support designed for the E26 mine were:
- To provide an abrasion resistant lining for the 130 drawpoints that would last the life of the Extraction Level.
- To construct a low maintenance environment and hence reduce ongoing operating costs.
- To ensure a safe working environment.

Shotcrete Design
The use of shotcrete in conjunction with the rockbolts and straps was essential in preventing...
deterioration of the pillars between drawpoints. These pillars were required to support the full column loading from the caved material (Figure 6). Any pillar loss would jeopardize the integrity of the drawpoint by reducing the amount of sidewall supporting the brow. It was anticipated that they would face several cycles of point loading and unloading during the caving process. Loading events include: large wedges, hang-ups, arching and the consolidation of material due to a static draw column [5]. For this reason, the inclusion of steel fibers in the shotcrete was seen as beneficial in coping with possible loading and unloading of the pillars.

The geotechnical consultants that were engaged on the project all recommended the use of reinforced shotcrete to support the production areas against the predicted mining-induced stresses. Some consultants suggested mesh reinforcing; however, by designing the advanced Undercut sublevel to provide stress cover, there was no requirement to install mesh-reinforced shotcrete, as is often used in conventional block cave operations where mining induced deformation occurs [2].

The possible failure modes of the excavated rock were investigated in order to derive the optimum shotcrete specifications for the block caving mining method.

It was recommended that the combination of shotcrete and mesh straps would provide a high resistance to shear failure.

**Specifications**

The SFRS was specified with the following compressive strengths:

- 20 MPa (2,000 psi) in 72 hours
- 30 MPa (4,350 psi) in 7 days
- 40 MPa (5,800 psi) in 28 days

Flexural strength was specified as:

- 4 MPa (580 psi) in 7 days
- 5 MPa (725 psi) in 28 days

Steel fibers were specified as ranging in length from 25 mm to 40 mm (1 to 1 1/2 in.). The aspect ratio was 50 minimum and 100 maximum. The amount of fibers was set at not less than 60 kg per m³ (100 lb./yd³).

These specifications were based on other mines experiences, including block cave operations.

The Main Decline to access the E26 orebody was started in October 1993. The area around the portal was sprayed with 25 MPa (3,600 psi) shotcrete to prevent loosening of the rock blocks. The first 18 m (60 ft.) of the decline was supported with steel sets. As the development passed through the surface weathered zone from 18 to 200 m (60 to 660 ft.) down the Decline, the backs (roof) and walls were shotcreted with a 50 mm (2 in.) thick covering of 40 MPa (5,800 psi) shotcrete.

Steel fiber reinforced shotcrete (SFRS) was applied as part of the Extraction Drive mining cycle (Figure 8), following after the development contractor had installed rockbolts, cablebolts and expanded metal mesh straps.

By using smoothwall blasting techniques and limiting the development round length to 3 m (10 ft.), the tight tolerances specified under the contract were achieved. To maintain the profile and prevent block fall out, the development contractor was required to keep rockbolt installation to within 4 m (13 ft.) of the face.

![Figure 2: E26 Mine Geology.](image)

![Figure 3: Block fallout from roof (backs).](image)
As the turn-outs for the drawpoints were excavated, SFRS was applied after every cut in order to maintain the integrity of the bullnose area, which had already been preconditioned by the Extraction Drive blasting (Figure 8). The coordination of this support required good communication between the development and shotcreting contractors.

**Major Underground Installations**

All of the long term mechanical and electrical installation excavations were sprayed with 100mm (4 in.) of 40 MPa (5,800 psi) SFRS to provide a safe, low maintenance working environment. These installations included:

- Crusher chambers
- Main Pump Station
- Underground Workshop and Control Room
- Screen Room
- Main Conveyor Decline
- Transfer Conveyor Drives
- Loading Station
- Shuttle Conveyor/Orebins area
- Substations

In the first crusher chamber the shotcrete was applied after the 17 m (55 ft.) high excavation was complete. The contractor managed to spray the whole chamber with one nozzleman operating from a cherry picker. For the second crusher the sequential excavation from top to bottom allowed campaigns of shotcreting between slices and resulted in better quality of finish.

All of the above installations have performed well with no maintenance of the SFRS required.

**Shotcrete for Safe Access**

During development of the 9700 Exploration Drive, the lowest level in the mine, the development contractor experienced mild rockburst conditions, with small volumes of rock bursting from the face. This occurred a few hours after blasting of the previous development round, usually during rockbolting. The measured stress levels in the area were relatively low with a principal stress of 30 MPa (4,300 psi), however the rock mass was brittle and highly jointed. Due to concern for safety of the jumbo operators, shotcreting was incorporated into the development cycle. After firing, watering down and mucking out enough buckets for access, the shotcreting contractor was brought in to apply 50 mm (2 in.) of SFRS to the face, backs (roof) and sidewalls of the unsupported round. The development contractor would then muck out the remainder of the blasted rock and bring in the jumbo to rockbolt through the shotcrete, with the operator working under supported ground. If further rock noise was heard, the shotcrete rig would spray the rest of the face and walls. By this application of SFRS, the ground was allowed controlled relaxation and excavation could proceed safely.

During retreat of the RL9818 Undercut sublevel the drill drive occasionally lost blocks from the top of the drive profile (brow). The higher backs (roof) resulted in a rill of blasted material preventing access to the next uphole ring. In order to provide safe access for the charging contractor, the rill was stabilised by spraying with shotcrete.

**Construction of Drawpoints with Shotcrete**

Over the 7 year life of the RL9800 Extraction Level, the production of ore will average 200,000 tonnes (220,000 tons) through each of the 130 drawpoints. The longevity of the Extraction Level drawpoints is critical for the success of a block caving operation. The mine can not afford to stop...
production to repair drawpoints. This is particularly so in Australia where labor costs are high compared to overseas caving operations that have large underground workforces.

The drawpoint lining system as used at Henderson Mine, a block caving operation in Colorado, U.S.A. was adapted for Northparkes conditions.

The ground support specified for the drawpoints included:

- Rockbolts, 2.4 m long (8 ft.), fully resin grouted on a 1.0 m x 1.0 m spacing (3 ft. x 3 ft.).
- Expamet straps installed longitudinally into the drawpoint from the Extraction Drive and also pinned vertically in the brow area (Figure 9).
- Cablebolts, 6.0 m long (20 ft.), fully cement grouted, installed in the brow area.
- Two steel sets fabricated from 250UC.
- The steel sets were encased in SFRS to provide a tough smooth lining system.

Each drawpoint is subjected to abrasion from the drilling ore resulting in wear to the sidewalls, along with impact from secondary blasting of oversize rocks and from the LHDs. Each drawpoint has final dimensions of 3.8 m wide by 3.2 m high (12.5 x 10.5 ft.). The SFRS specified for the drawpoints had to be tough to withstand these operating conditions, hence the addition of steel fibers.

**Drawpoint Construction Cycle**

The excavation of each drawpoint requiring the steel set lining system commenced with a stripping round taken from the previously supported Extraction Drive. The bullnose was then bolted, strapped and shotcreted before the second stripping cut was taken to square up the face. After this cut the sidewalls and backs were again bolted, strapped and shotcreted, as in Figure 8. The next stage was to install two 6.0 m long (20 ft.) single strand cablebolts in the backs and allow to cure for 24 hours before the first full face cut was taken. The next application of SFRS only occurred once the drawpoint was fully developed and the steel sets were erected and secured (Figure 10). Working from the bottom up, the sets were completely encased in SFRS up to the top beam level. Up to 600 mm (2 ft.) thickness of shotcrete was applied. While this may seem an expensive way to place mass concrete, the time taken was substantially quicker than forming and pumping concrete around the sets.

As a trial, the first four drawpoint steel sets were erected, formed, pumped with concrete and stripped. Each drawpoint took 4 days to complete. By using SFRS, this part of the construction process was reduced to one day (one shift to erect, one half-shift to spray each drawpoint).

The final stage in the drawpoint construction process was to form up the section above the top beam and pump full with 32 MPa (4,600 psi) concrete. This concrete plug acts as wear point for the brow area.

**LHD Cable Protection**

One problem that was not initially identified was the damage caused to the trailing cables of the electric LHDs by the steel fibers in the shotcrete. As each LHD trans from its anchor point to the drawpoints, the trailing cable spools out from the rear of the unit on to the concrete floor (Figure 11). As the LHD turns corners, the cable brushes against the SFRS covered wall. To minimize this problem, the corners of the drives were sprayed with a plain shotcrete (no fibers) which was then hand-trowelled to a smooth finish. A low wear surface was thus provided for the cable to roll against.

**Sealing for Water Storage**

To provide the Main Pump Station with a positive suction head and also 400 kl (1.050 gal.) storage capacity, a 4.0 m (13 ft.) diameter, 31.0 m (100 ft.) high sump was...
excavated by raisebore and strip. Shotcrete was chosen as the permanent lining for the sump as it was easy and quick to apply and could be made almost impermeable by the addition of silica fume.

The sump shotcrete was specified as follows:
- Minimum thickness = 100 mm (4 in.)
- Compressive strength = 50 MPa (7,250 psi)
- Silica fume content = 60 kg/m$^3$ (100 lb./yd$^3$)
- Steel fiber content = 40 kg/m$^3$ (67 lb./yd$^3$)

Although the shotcrete specifications were satisfied, the interface between the shotcrete lining and the concrete supporting structure at the base of the sump was poor and leaks occurred initially. However, observations indicate that the fines content of the mine water has sealed the leakage paths.

**The Shotcrete Contract**

The contract required that the quality of the work be controlled through the operation of a quality system conforming to the requirements of Australian Standard AS3902. The contractor was required to submit the following documents:
- Contract Quality Manual
- Inspection and Test Plans (ITP)
- Detailed work procedures

The contractor was required to carry out its own inspection and testing for quality control and assurance. However, the superintendent had the right to make its own arrangements for check testing and auditing.

The contractor undertook depth testing of the freshly sprayed SFRS by use of a spike inserted into the backs and walls every square meter. Northparkes Mines noted that the minimum specified thickness was often exceeded in order to ensure the depth was achieved over the whole area.

Trial mix testing was carried out by the contractor before any application of SFRS for the Works. The test results were then submitted for approval by the superintendent. Test panels were sprayed, cured, and cored for testing.

During the actual construction, the contractor was required to spray one test panel for every 25 m$^3$ (33 yd$^3$) of SFRS applied. From each panel, four 75 mm (3 in.) diameter cores were taken for compressive strength testing at 3 days, 7 days and two at 28 days. The superintendent could also direct the contractor to take in-situ cores for compressive strength testing.

The contract was based on a schedule of rates with a cost per square meter for minimum thicknesses of 50 mm (2 in.) and 75 mm (3 in.) submitted by the contractor. The measurement of quantities was to be based on design profiles or areas. It was recognized that the measurement of “as-built” areas is a notorious area for disagreement and can only be accurately determined by Optech pick-ups or many survey profiles. Northparkes Mines realized that this arrangement would put all the risk with the contractor to ensure that the required thicknesses were met; however it was assumed that management of the contract would be easier.

**Equipment**

The main contractor used two shotcreting rigs based on Bobcats as the carrier (Figure 12). Each rig incorporated a Shot-Tech Robotic spraying arm on a maxilift boom and towed a Jacon sidewinder pump behind. A Jacon Midjet rig was also utilized.

The small plant size allowed the contractor to quickly set up and spray multiple drawpoint sites during a shift.

**Supervision and Coordination**

Weekly meetings were held to review progress for the period and to draft plans for the next period. These plans changed almost on a daily basis due to the complex interfaces between the various activities.
occurring underground. On the Extraction Level different contractors were carrying out the following contracts:
- Drawpoint development and ground support installation
- Steel set erection
- Drawbell rising
- Concrete roadway installation
- Communication system reticulation
- Drill & blast of drawbells

As the drawbells were brought into production, Northparkes Mines commenced production with diesel powered LHDs, resulting in many activities in a relatively small work area with each resource having their own distinct priorities.

In order to coordinate these activities, a daily production/coordination meeting was held in the underground offices. The contractors gained a better understanding of the interface and scheduling of activities and realized that if they all worked together they would all finish quicker. A major improvement took place in relations between the contractor and production supervisory staff along with acceleration in the overall works and a noticeable raising of quality standards. Towards the end of the Extraction Level construction, the contractors were actually running the meeting without the superintendent being present [6]. The application of the QA system was seen as essential when large quantities of shotcrete are applied on a 24 hour basis.

**Batch Plant**
All shotcrete and concrete was batched on the surface and transported to the application site by 4WD concrete agitator trucks (Figure 13). The trucks were able to reverse straight up to the shotcrete rig at all locations. The round trip from the batch plant to the Extraction Level underground and back was approximately 11 km (7 mi.). During the peak construction periods, there were delays in the Main Decline and on the Extraction Level due to the number of vehicles in the mine. For the next stage of mining, an underground batch plant would be appropriate.

**Contractor Performance**
All of the shotcreting companies used at the E26 Project performed well. The main contractor sprayed a total of 11,288 m³ (400,000 yd³) over a period of 16 months. The best production was 40 m³ (52 yd³) in a 10 hour shift from one unit. During the peak times two units sprayed on a 24 hour per day, 7 days a week basis.

**Shotcrete Performance**
The installed drawpoint lining system at Northparkes E26 Mine is performing well with no repairs being necessary in the actual drawpoints to date.

As shown in Figure 14, some wear of the SFRS is evident between the steel sets, apparently due to the abrasion of the rilling ore as it flows through. However, as long as the LHDs are able to continue drawing material from the drawpoint it is not planned to re-spray the walls. For the next
stage of mining, a tougher lining system will be investigated.

Conclusions
During the 4-year construction period for the E26 Underground Mine, shotcrete was used for many applications, proving itself as a versatile material that was quick and easy to apply.

By shotcreting the Extraction Level, the mechanical installations and other openings subject to mining stresses, a low maintenance environment has been constructed. Operating costs are therefore minimized and Northparkes E26 Mine continues to produce at the lowest cost per tonne of all Australian underground mines. In the 1997/98 financial year, 4,035,000 tonnes (4,450,000 tons) were hoisted against a plan of 3,900,00 tonnes (4,300,000 tons).

The specification of a high strength, tough lining system for the drawpoints ensures that the high production rates are maintained.

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Stephen Duffield is a Mining Engineer who graduated from University College, Cardiff, Wales in 1984. He was a shift boss and jumbo operator on a tunneling contract in Scotland before travelling to Australia in 1988. Since then, Stephen has worked on underground construction projects for both mining contractors and mining companies, including Costain, Thiess-Thyssen, Pasminco and now North Mining. He has been employed at Northparkes Mines since 1995, where he supervised the construction of the block cave mine from decline development through to the milestone of reaching full production in 1997. Stephen is currently Senior Mining Engineer in the Feasibility Study Team, which is responsible for designing the next stage of underground mining at Northparkes Mines.

References


