Cold Weather Shotcrete in Canada's North Country

by Richard Atkinson and Michael W. Martin

The Canadian mining industry has been experiencing a renaissance recently and part of this is the discovery of diamond deposits in the Northwest Territories. The terrain and isolation of the Northwest Territories makes developing these mines challenging. The climate places particular demands on shotcrete application and cure. As part of the life of mine plan at the EKATI Diamond Mine, a transition from open pit to a combination of open pit and underground mine was required. The Koala North pipe was selected for use as a trial mine to test both mining methods and ground support systems. The use of shotcrete was identified as the preferred method to stabilize kimberlite ore drives. Procon Mining and Tunnelling Ltd was the contractor retained by the company to develop the Koala North underground test mine. The mining contractor contacted Target Products Limited (in November 2001) to help develop and implement the shotcrete test programs.

The two main problems facing Target/Procon on this shotcrete development and implementation project were the isolation of the mine site and the relatively low temperatures that the shotcrete would be placed in (and expected to cure in).

Dealing with Isolation and Delivery Issues

The mine site is 900 mi (300 km) northeast of Yellowknife. It is serviced by air transportation for 12 months of the year and an ice road (a road literally built of ice over the frozen lakes and tundra) from late January to mid March. All heavy construction materials for the entire year must be moved into the site on the ice road during this short period (Fig. 1). The proposed development requirements of the test mine meant that the shotcrete volume for the first year could be met by shipping bagged shotcrete product on the ice road. The volumes required in subsequent years, however, were greater than could possibly be economically met by this supply method. For this reason, a decision was made to construct a shotcrete manufacturing plant at the mine site that used local aggregates, using bagged shotcrete concentrate. The shotcrete batch plant was designed, prefabricated, shipped into the site over the winter 2002 ice road, and subsequently assembled and commissioned prior to the bagged shotcrete supply running out (Fig. 2). This project was managed by Target's equipment manufacturing arm and is discussed in this article.

Fig. 1: Trucks moving material to the site over the "ice road"

Dealing with Cold Climate Shotcrete Issues

The Koala North trial mine did not run with a mine air heating system; this partially drove the requirement for a shotcrete product that had to achieve initial set in approximately 10 minutes and achieve a minimum compressive strength of 1200 psi (8 MPa) in 8 hours at an ambient temperature between 5 and –4 °F (–15 and –20 °C). A dry shotcrete application method was agreed to with the mine owner. With these objectives in mind (in early December 2001), Target's materials laboratory in conjunction with DEH Consultants developed a laboratory testing program to investigate several different shotcrete concentrate mixture designs and shotcrete additives.

The first series of bench trials (held in late November 2001) were conducted in two phases. Phase 1 investigated different cement and accelerator combinations. In these tests, to ensure temperature control, all materials were preconditioned to 54 °F (12 °C) with water at 34 °F (1 °C) and the casting equipment at 1 °F (–17 °C). All cast samples were stored in a freezer at 1 °F (–17 °C). The results shown in Table 1 clearly indicated that the objectives were met by Mixture Design 1. Mixture Design 3 just failed the 8-hour strength requirement but had superior 6-day strength gain (compared with Mixture Design 1).

Fig. 2: Shotcrete manufacturing plant uses local aggregates and a concentrate shipped in over the ice road

Table 1: Preliminary Shotcrete Trials

Shotcrete property	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Set time, minutes	<10	<10	<10	<10
8-hour strength	1500 psi (10 MPa)	700 psi (5 MPa)	1000 psi (7 MPa)	400 psi (3 MPa)
24-hour strength	1900 psi (13 MPa)	1300 psi (9 MPa)	1700 psi (12 MPa)	600 psi (4 MPa)
6-day strength	2100 psi (15 MPa)	1300 psi* (9 MPa*)	3200 psi (22 MPa)	600 psi (4 MPa)

*Lower 6-day strengths probably due to defects in casting of cube.

After discussing these results with the contractor and comparing the costs of the various mixture designs, the following series of decisions were made about which direction to proceed with the Phase 2 tests:

- Mixture 1 had met all of the original requirements but was significantly more expensive than the other mixtures; therefore rejected for economic reasons;
- Mixture 2 could potentially be made to work but would require more development time than the timetable allowed; it was rejected on this basis alone;
- Mixture 3 could definitely meet the requirements with minor adjustments; and
- Mixture 4 could meet the requirements with a lot of modification and some changes in the

Fig. 3: Shotcrete predampener and gun

requirements. It was felt, however, that Mixture Design 4 should receive further investigation as it was the least expensive mixture.

Phase 2, conducted in mid-December 2001, tested the impact of preheating the shotcrete mixture to 59 °F (15 °C) and using heated water at 54 °F (12 °C) on modified Mixture Designs 3 and 4. The driver for this was the fact that storing the product in a heated warehouse was less than the cost differential between Mixture Design 1 and these two mixtures.

As expected, the results of these tests showed that the early strength of the in-place product was significantly affected by the temperature of the mixture water and the starting temperature of the dry-mix product.

The results of Phase 2 gave a good degree of confidence that an actual trial shoot with modified versions of Mixture Design 4, now called Mixture 10 and Mixture 11, would be successful.

A trial shotcrete shooting program was conducted in mid-January 2002 at Target's Morinville Alberta yard under the supervision of AMEC materials testing personnel.

The site conditions at the time of the trial were as follows:

- Ambient air temperature: 18 to 21 °F (–8 to –6 °C);
- Water temperature: 54 to 57 °F (12 to 14 °C); and
- Dry-mix temperature: 54 to 57 °F (12 to 14 °C).

Within 15 minutes of being shot, the beams used for early-age strength testing were placed into a freezer at 10 °F (–12 °C).

The results of the test shoot are shown in Table 2.

The results of this testing indicated that either of these mixtures could meet the contractor's and owner's requirement. Following acceptance of the product, the shotcrete concentrate product was manufactured in time to be shipped in over the ice road in mid-February to mid-March 2002.

Conclusions

1. Dry-mix shotcrete can be manufactured and applied in extreme conditions and remote sites at reasonable cost;
2. Realistic total cost and life cycle assessments provided the path to the selection of the final shotcrete concentrate mixture design; and
3. Coordination and cooperation between the contractor, owner, material/equipment supplier, testing laboratory, and consultants were critical to this project being successfully completed in a very short time.

Post 2002 Update

The use of shotcrete at the EKATI Diamond Mine's Koala North trial mine proved to be successful. A shotcrete concentrate is now shipped into the site to be processed with locally sourced aggregates, reducing product costs and associated ice road traffic volumes. Shotcrete usage at the mine site has increased with the recent commissioning of the Panda underground mine and the approval of the Koala underground mine. This volume increase has necessitated an upgrade of the shotcrete batch plant.

Table 2: Shotcrete Trials Compressive Strength Test Results

Shotcrete Properties	Mixture 10	Mixture 11
8-hour strength	1300 psi (9 MPa)	1300 psi (9 MPa)
12-hour strength	1600 psi (11 MPa)	2300 psi (16 MPa)
24-hour strength	2000 psi (14 MPa)	N/A
3-day strength	3500 psi (24 MPa)	5000 psi (36 MPa)
7-day strength	4800 psi (33 MPa)	5500 psi (38 MPa)

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