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USE OF SHOTCRETE TO CONTROL ACID MINE DRAINAGE IN WASTE ROCK PILES

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ABSTRACT

A research program supported by Westmin Resources and the Mineral Development Agreement (MDA), has evaluated the use of cementitious dry surface covers in the prevention of water and oxygen infiltration into acid waste rock piles. This paper presents the results of a field trial of a dry cover over a large test area on a waste rock pile at the Westmin Myra Falls site. The field trial was supported by Westmin Resources and CANMET under the Mine Environment Neutral Drainage (MEND) program. The objectives of this study were to apply the cementitious cover in the most cost effective manner and to evaluate the material properties and the long term efficacy of the cover system. Approximately 3500 square metres of area was covered using the shotcrete process. A robotic arm mounted onto a vehicle was used to apply the shotcrete onto the rock slope. The cementitious material used in the project incorporated high volumes of fly ash (a waste product) to reduce the material cost. The shotcrete mix also included the use of polypropylene fibres to control cracks. The test area was instrumented with infiltration boxes and survey markers to monitor seepage through the shotcrete and settlement in the rock slope. The performance of this test area will be monitored over the subsequent years to evaluate the long term durability of this cover when subjected to field conditions.

INTRODUCTION

The Westmin Myra Falls mine site is located in a narrow steep valley in the central region of Vancouver Island, British Columbia. Most of the waste rock from the mining operations has been placed in dumps constructed along the north valley wall, east of the inactive open pit. The waste rock dumps contain sulphide minerals and have been generating acid drainage with elevated loadings, particularly zinc, copper, and cadmium for at least a decade. A water collection and treatment system is presently in place to protect the downstream environment (Myra Creek); however, reclamation of the waste rock dumps and the eventual decommissioning of the mine will require long term control method for acid generation and drainage at the mine site. Ideally the long term control should restrict the availability and contact of oxygen and water, the primary ingredients of acid generation process, with the reactive waste rock.

The 1992 hydrogeology report prepared by Northwest Geochem as part of the mine decommissioning plan recommended the closure strategy for the waste rock dump focus on preventing acidic water from moving downward to the water table. Restricting the access of surface water infiltration and oxygen to reactive waste rock can be achieved using covers and seals. The restriction of water can also serve to limit both the formation of acid and the subsequent transportation of the oxidation products away from the source (Draft ARD Technical Guide, 1989). A variety of materials have been proposed to provide surface covers for reactive waste rock or tailings, including: soils, synthetic membranes, compacted clay and till, asphalt, and concrete. The draft ARD Technical Guide (1989) and Malhotra (1991) discuss the relative advantages and disadvantages of the various types of surface covers.

One of the major problems with the use of various materials proposed for use as surface covers is the cost associated with large scale application (Malhotra, et al., 1990). Conventional Portland cement concrete shotcrete is a well known technology for stabilizing vertical rock faces and other difficult access areas. Shotcrete is a process where concrete is shot into place by means of compressed air. However, this type of system becomes too expensive for large areas where adequate mesh reinforcement, control joints and increased thickness is required to provide adequate cover for the reinforcement.

Recent studies by CANMET and others (Morgan and McAskill, 1990; Langley and Dibble, 1990; Seabrook, 1992) have shown that a fibre-reinforced, high volume fly ash shotcrete concrete can be used successfully in large-scale applications. The system incorporates discrete polypropylene fibres to increase to increase toughness and inhibit cracking and uses large volumes of fly ash to lower material cost. A limited number of field trials have been conducted but more data is required to determine the long term effectiveness of the proposed capping systems.

Northwest Geochem, in conjunction with Powertech Labs Inc. has concurrently been researching, developing and testing a cementitious cover which incorporates mine tailings. Laboratory trial mixes and limited small scale tests have been shown that there is great potential in this type of capping system (Gerencher et. al., 1991).

This paper will present the results of a field testing program to perform a large scale test to apply a shotcrete cover on a portion of the waste rock dump. The main objective of the test is to evaluate material properties and the long term efficacy of the field placed shotcrete. In addition, the large scale test provides an opportunity to develop and use the best practicable technology to install the shotcrete concrete cover material on reactive waste rock. This test represents an open-ended system, therefore the effectiveness of large scale cover placement on restriction of acid generation and drainage was not evaluated in this test and detailed instrumentation to monitor ARD parameters were not installed.

TEST PROGRAM

Site Preparation

The large scale shotcrete test was performed on the northeast end of the dump. This area of the waste rock dump was not benched and has a slope between 37°-39°. It was decided to reslope the upper 10 m of the dump to a grade of 22°. Although shotcrete placement can occur on vertical slopes, the shallower grade was required for the use of the robotic arm shotcrete spraying equipment and subsequent placement of overburden and vegetation on the shotcrete capping system.

The test site was resloped as shown in Figure 1. An 8 m wide access road was constructed at the base of the test slope. The approximate area of the test site was 3500 m^2. It was decided to connect the capping system to the diversion ditch. After resloping, the test area was compacted using a vibrating Bomag roller.

Materials

One of the largest costs in using a cementitious dry cover is the transportation of raw materials such as aggregate and cement to the site. In a previous study by Northwest Geochem and Powertech (Gerencher et al.), coarse mine tailings was used as an aggregate in the shotcrete mix and thus eliminating the need to import aggregate from Campbell River. The study showed that mine tailings can be used effectively in a dry cover. However, the coarse tailings are also used as mine backfill and may not be available for reclamation use. It is envisaged that during the final reclamation, the crushers at the mine can produce aggregate to be used for shotcrete. The concrete can then be batched directly on site. For the current field trial, it was not economical to set up a concrete batching plant on site. The proportioned aggregate along with the fly ash and water were trucked from Campbell River in ready-mix trucks. Each truck contained 6 m^3 of aggregate. The cement, packed in 834 kg sacks, was added to the truck on site.

The mix proportions are shown in Table 1.

TABLE 1
Proportions for Primary Mix

	kg/m^3
Type 10 Cement	139
Fly ash (Centralia)	217
Concrete sand (<5 mm) SSD	1815
Water (w/c ratio = 0.38)	138
Polypropylene fibres	4

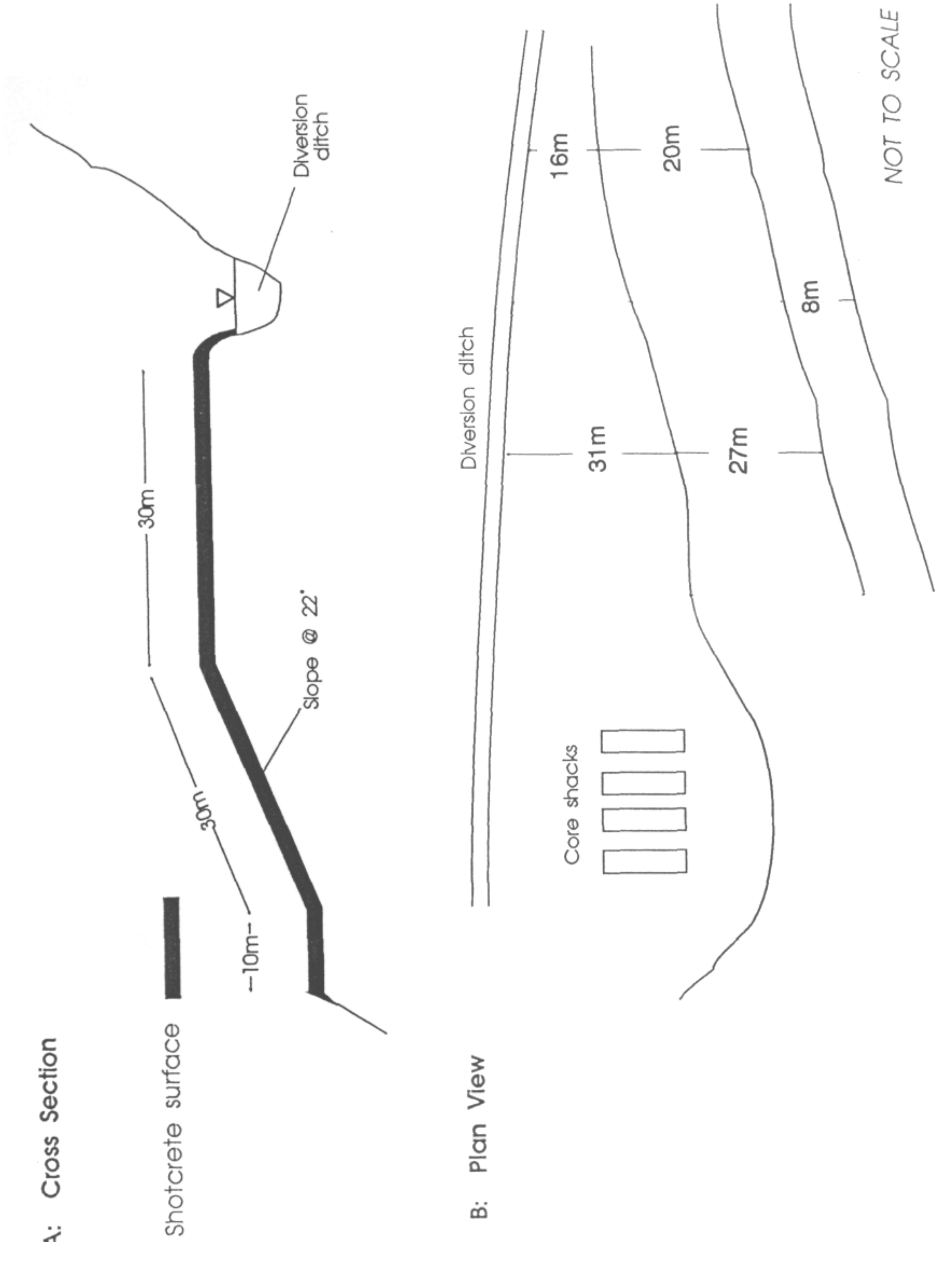


FIGURE 1 Schematic of Large Scale Field Application of Shotcrete Concrete

The mix design was chosen with emphasis on optimizing the material costs. Cement is most expensive material in a shotcrete mix. Fly ash, a waste product from coal fired power generating plants, can be used as a partial replacement for cement.

Approximately 100 m^2 of the trial area were covered with a mix containing tailings (Table 2). Since there were no weighing facilities on site the mix had the tailings added volumetrically which resulted in a less accurate batch. The tailings did not blend properly with the cementitious material and thus resulted in a higher water demand in order to extract the mix from the truck.

TABLE 2
Proportions for Tailings Mix

	kg/m^3
Type 10 cement	167
Fly ash	174
Tailings	1500
Polypropylene fibres	4
Water	260

Equipment

Another major cost of this dry cover system is the application of the shotcrete. In Westmin's final closure plan, the approximate area required to be covered is 6 hectares. Therefore it is imperative that equipment be used which can produce consistent quality shotcrete at very high production rates. The wet mix shotcrete in this project was applied using a robotic arm mounted on a rubber wheel carrier. The robotic arm, shown in Figures 2 and 3, is mounted on a turret which has a 360° swing. The spray boom has a reach of 10.4 m. The shotcrete nozzle, attached to the end of the spray boom, is able to tilt 120° and has a rotation of 270°. The wet-mix concrete was pumped to the nozzle using a diesel powered double piston shotcrete pump through a 63.5 mm diameter delivery hose. The arm is remotely controlled by an operator using a series of toggle controls.

Application of Shotcrete

The shotcrete test trial was performed during August, 1992. The crew consisted of one nozzleman, one helper, and one pumpman. All the equipment did not require any major assembly and were mobilized in only a few hours.

The cement was added to the concrete trucks on site and were allowed to mix for at least 30 minutes. The concrete was then discharged into the hopper of the shotcrete pump. The pumpman controlled the amount of shotcrete supplied to the nozzle. The nozzleman controlled the shotcrete nozzle and the placement of the shotcrete onto the waste rock.

The common spraying sequence started with the boom fully extended at its maximum

Figure 2 Application of Shotcrete on Test Site Using Robotic Arm.

Figure 3 View of Robotic Arm During Shotcrete Application.

reach. The nozzle was usually positioned approximately 1-1.5 m from the surface. The boom was then swung side to side in a sweeping motion and was slightly retracted after each sweep. The nominal thickness of the shotcrete was chosen to be 75 mm. Approximately 80 to 90 square metres were covered without requiring to move the vehicle. Due to the relatively smooth surface produced by the compaction of the waste rock the thickness of the shotcrete cover was quite consistent.

The production rates achieved in this test program was quite high. The entire test cover took approximately 5 days to install. The average rate achieved was 150 m^2/hour. On some occasions production rates of 200 m^2/hour were achieved.

Seven shotcrete panels 1m x 1m x 150 mm were prepared for laboratory testing.

<u>Instrumentation</u>

Prior to the shotcrete application, 13 infiltration boxes were installed at various locations in the test area. An extra infiltration box was installed in the waste rock dump outside the test area for comparison. After the application of the shotcrete, a grid of survey makers were install onto the cover at 5 m spacings.

<u>Laboratory Testing</u>

A number of laboratory tests were performed to characterize the quality of the shotcrete cover.

Cylinders 150 mm in diameter and 300 in length were cored from the test panels for compressive strength testing at various ages of curing. Figure 4 shows the results of the tests. Panels 4 and 5 were shot using the tailings mix.

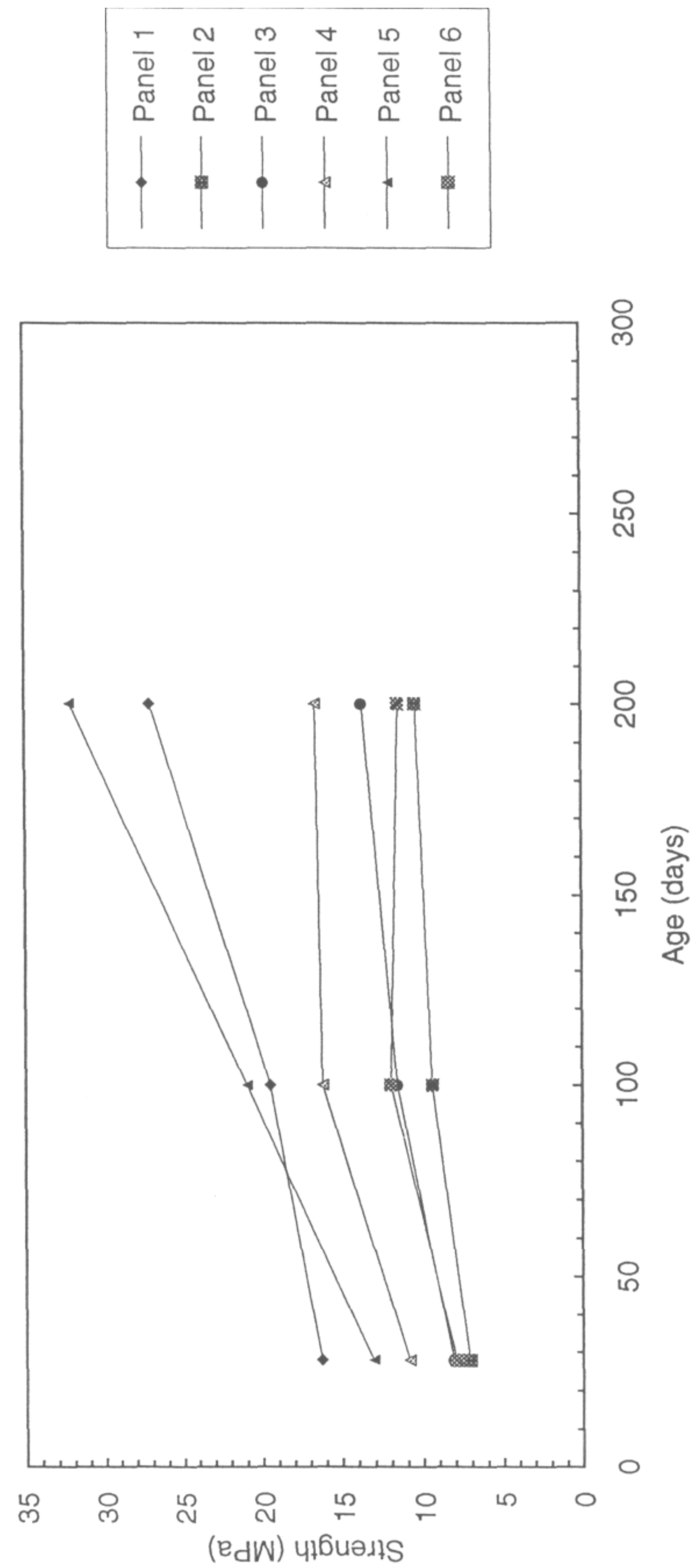
Concrete is a brittle material exhibiting very low tensile strengths. Therefore, unreinforced concrete will tend to crack and separate following small deflections. Flexural tests were performed on beams cut from the shotcrete panels. Table 3 shows the results of the flexural tests at 100 days cure.

TABLE 3
Properties of Shotcrete at 1 00 Days Cure

	Primary Mix	Tailings Mix
Compressive Strength (MPa)	9.4-19.5	16.2-21
Flexural Strength (MPa)	1.5-2.0	2.9 - 3.1
Ductility Toughness Index I_5 Toughness Index I_{10}	 1.6-2.7 2.7-5	 1.4 2.2 - 2.5
Boiled Absorption (%)	10.2- 10.9	13.4- 14.3

FIGURE 4

COMPRESSIVE STRENGTH OF SHOTCRETE



Monitoring Program

The shotcrete capping system will be subjected to the following monitoring program on an annual basis in order to evaluate its performance:

- moisture levels in the infiltration boxes will be monitored;
- visual inspection to observe cracks, oxidation, freeze-thaw damage;
- survey for slope settlement and lateral movement of the slope;
- obtain concrete cores for strength tests.

DISCUSSION

A major consideration in the design of the testing program was cost. Table 4 shows a breakdown of the cost of the project.

TABLE 4
Cost Breakdown of Shotcrete Application

	Cost/m^2
Cement	$1.28
Fibres	$1.88
Fly ash	$1.40
Aggregate transported to site in ready-mix trucks	$7.10
Labour	$3.30
Equipment	$3.50

It is apparent that a primary cost involves the transportation of aggregate to the mine site. Therefore if a local aggregate source was available the unit cost per square meter could be less than twelve dollars.

As a surface sealant, high strength shotcrete is not required as long as it prevents water and oxygen from reaching the reactive waste rock. The design objective was to achieve 15 -20 MPa in compressive strength. The cores from the test panels, after 100 days of curing, achieved as high as 19.5 MPa, however there appears to be a variance in the quality of the mix as some of the strengths measured were as low as 9.4 MPa. The inclusion of a superplastizer would reduce this spread. The relatively low strength characteristics of these materials is reflected in the high values measured in the boiled absorption test. These results reflect the low cementitious content of the design mixes, which were chosen in order to reduce costs of materials. The lower strength characteristics of this design mix are not a concern due to the low water flow can be expected through this portion of the dump and the site preparation which should result in little ground movement.

Due to the low cementitious content and the lower fibre content the cover did experience some cracking due to shrinkage. Most of these cracks were subsequently filled with a cement slurry and further cracking has not been observed. Another factor contributing to the cracking was the high ambient temperatures during application.

The durability of the in place shotcrete will be assessed in future inspections, and modifications to the design mix will be made before large scale application of this technology.

The use of robotic application techniques resulted in high production rates. However this type of equipment was originally designed for lining tunnels and the movements of the boom are not suited for application on near level grades. For example, the swinging motion of the arm resulted in wear on the clutch in the turret. Another improvement which would make the shotcrete application more efficient would be to use a smaller, more mobile vehicle which could easily traverse the shallow slopes.

There is potential to further enhance productivity by using a larger diameter delivery hose. For example, the use of a 75 mm diameter delivery hose (versus the 63.5 mm hose used in this application) would increase production by at least 30 per cent. The use of a larger hose would also reduce the plugging of the lines which was a concern in this project.

Conclusions

This study has shown that shotcrete dry covers can be a viable option for sealing waste rock dumps to control acid rock drainage. The application using a robotic spray boom resulted in high productivity. A major proportion of the cost was involved in the importation of aggregate. The use of a local aggregate source would make this process more cost effective than other types of covers. The use of the robotic system also indicated areas for potential improvement of the equipment.

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