SHOTCRETE AS A CEMENTITIOUS COVER FOR ACID GENERATING WASTE ROCK PILES[1]

C.E. Jones[2] and J.Y. Wong[3]

Abstract: A research program supported by both Westmin Resources and the Canada-British Columbia Mineral Development Agreement (MDA) has evaluated the use of cementitious dry surface covers for the prevention of water and oxygen infiltration into acid-generating 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 near Campbell River, BC, Canada. 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 3,500 m^2 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 fibers to control cracks. Costs of materials and application of the cover were determined. The test area was instrumented with survey markers to monitor settlement in the rock slope. The performance of the test area was monitored for 1 yr to evaluate the durability of this cover when subjected to field conditions. Compressive strength increased over the 1 yr period, and all samples achieved or exceeded the design criteria. Some plastic shrinkage cracks were observed in the shotcrete immediately after application but after 1 yr of exposure these cracks did not appear to have expanded.

Introduction

The Westmin Resources Limited, Myra Falls Operations is a 3,650 mt/d copper-zinc-gold-silver mine located in a narrow steep valley in the central region of Vancouver Island, BC. The climate of the site is classed as Marine West Coast by the Koppen system, with a mean annual precipitation of approximately 300 cm, with over 75% of the total precipitation occurring between October and March. 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 sulfide minerals and have been generating acid drainage with elevated metal 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; however, reclamation of the waste rock dumps and the eventual decommissioning of the mine will require a long-term control method for acid generation and drainage at the mine site. Ideally the long-term control method should restrict the availability and contact of oxygen and water, the primary ingredients of the acid generation process, with the reactive waste rock.

The mine's decommissioning plan recommended that the closure strategy for the waste rock dump focus on preventing acidic water from moving downward to the water table (C.E. Jones and Associates Ltd. 1992). Restricting the access of oxygen and surface water infiltration to reactive waste rock can be achieved using covers and seals. The restriction of water can potentially reduce the formation of acid and the subsequent transportation of the oxidation products away from the source (BC Acid Mine Drainage Task Force, 1989). A variety of materials have been proposed to provide covers for reactive waste rock or tailings, including soils, synthetic membranes, compacted clay and till, asphalt, and concrete. The draft ARD (Acid Rock Drainage)

---

[1]Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

[2]Carol E. Jones, Principal, Northwest Geochem, a division of C.E. Jones and Associates Ltd., Victoria, BC, Canada.

[3]Joe Y. Wong, Materials Engineer, Powertech Labs, Surrey, BC, Canada.

Proceedings America Society of Mining and Reclamation, 1994 pp 104-112
DOI: 10.21000/JASMR94020104

https://doi.org/10.21000/JASMR94020104

Technical Guide (BC Acid Mine Drainage Task Force, 1989) and Malhotra (1991) discuss the relative advantages and disadvantages of the various types of covers.

A limiting factor governing the use of various materials proposed for use as covers is the cost associated with large-scale application (Malhotra et al. 1990). Conventional portland cement shotcrete is a well known technology for stabilizing vertical rock faces; however, this type of system becomes expensive for application on large areas where control joints, mesh reinforcement, and increased thickness are required.

Recent studies by CANMET and others (Morgan and McAskill 1990; Langley and Dibble 1990; Seabrook 1992) have shown that a fiber-reinforced, high-volume fly ash shotcrete can be used successfully in large-scale applications. The system incorporates discrete polypropylene fibers 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 are required to determine the long-term effectiveness of the proposed capping systems.

Northwest Geochem, in conjunction with Powertech Labs Inc., has been researching, developing, and testing a cementitious cover that incorporates mine tailings. Laboratory trial mixes and limited small scale tests have indicated that there is great potential in this type of capping system (Gerencher et al. 1991). These trials also evaluated the effects of addition of fibers and fly ash to the shotcrete mix.

This paper presents the results of a large-scale test in which a shotcrete cover was applied to a portion of a waste rock dump. The primary objective of the test was to evaluate material properties and the long-term efficacy of the field-placed shotcrete. In addition, a large-scale test provides an opportunity to develop and use the best practicable technology to install a shotcrete cover material on reactive waste rock. This test site represents an open-ended system; therefore the effectiveness of large scale cover placement on restriction of acid generation and drainage was not evaluated, and detailed instrumentation to monitor ARD parameters was not installed.

Methods

Site Preparation

The shotcrete test was performed on an area of the waste rock dump which was not benched and had a slope between 37° and 39°. To facilitate this test, the upper 10 m of the dump was resloped to a grade of 22° (figure 1). After resloping, the test area was compacted using a vibrating Bomag roller. Although shotcrete can be applied to vertical slopes, the shallower grade was required for the use of the robotic arm shotcrete spraying equipment and subsequent placement of overburden and vegetation planned for the test area. An 8-m-wide access road was constructed at the base of the test slope. The approximate area of the test site was 3,500 m^2. The capping system was designed to connect with a diversion ditch that extends around the perimeter of the mine area.

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. 1991), coarse mine tailings were used as an aggregate in the shotcrete mix and would eliminate the need to import aggregate from Campbell River (located 85 km from the mine site). That study indicated that mine tailings can be used effectively as aggregate in a cementitious 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 will produce an aggregate to be used for shotcrete covers. The concrete can then be batched directly on site. For this field trial, it was not economical to set up a concrete batch plant on site. The proportioned aggregate along with the fly ash and water were trucked from Campbell River in

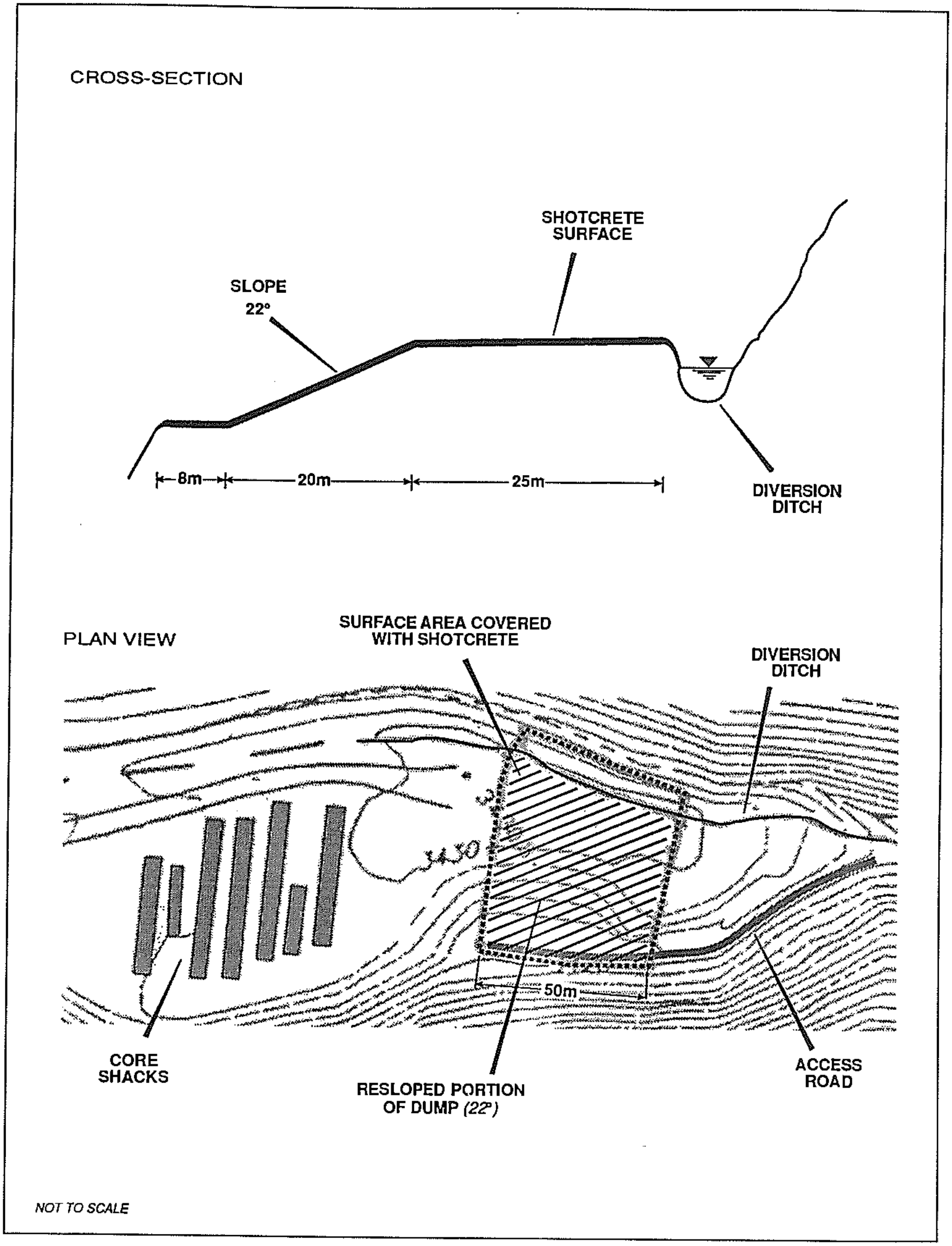

Figure 1. Schematic of large scale field application of shotcrete.

ready-mix trucks. Each truck contained 6 m^3 of aggregate. The cement was added to the truck on site. The mix proportions are given in table 1. The mix design was chosen with emphasis on optimizing the material costs. Since cement is an expensive material in a shotcrete mix, fly ash, a waste product from coal-fired power-generating plants, was used as a partial replacement for cement.

Approximately 100 m^2 of the test area were covered with a mix where coarse tailings were substituted for concrete sand (table 2). Since weighing facilities were not available on site, the tailings were added volumetrically, which resulted in a less accurate batch. The tailings did not blend well with the cementitious material and required a high water content to allow the mix to flow from the truck.

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 ha. Therefore it is imperative that equipment be used that 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-wheeled carrier. The robotic arm is mounted on a turret with 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 was applied during August 1992. The crew consisted of one nozzleman, one helper, and one pumpman. The equipment did not require any major assembly and was mobilized in only a few hours.

The cement was added to the concrete trucks on site and was allowed to mix for at least 30 min. 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 dump.

Table 1. Proportions for primary mix.

	kg/m^3
Type 10 cement	139
Fly ash	217
Concrete sand (<5 mm)	1,815
Water (water/cement ratio = 0.38)	138
Polypropylene fibers	4

Table 2. Proportions for tailings mix.

	kg/m^3
Type 10 cement	167
Fly ash	174
Tailings	1,500
Water (water/cement ratio = 0.76)	260
Polypropylene fibers	4

The common spraying sequence started with the boom fully extended at its maximum reach. The nozzle was usually positioned approximately 1 to 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. A nominal thickness of 75 mm of shotcrete was chosen for this test. Approximately 80 to 90 m^2 were covered without having to move the vehicle. Owing to the relatively smooth surface produced by the compaction of the waste rock, the thickness of the shotcrete cover was quite uniform.

The production rates achieved in this test program were higher than production rates achieved using conventional application methods. The entire test cover took approximately 5 days to install. The average rate achieved was 150 m^2/h. On some occasions production rates of 200 m^2/h were achieved. 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 that would make the shotcrete application more efficient would be to use a smaller, more mobile vehicle that 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%. The use of a larger hose would also reduce the plugging of the lines, which was a concern in this project.

Instrumentation

After the application of the shotcrete, a grid of survey markers was installed onto the cover at 5 m spacings and survey locations were determined.

Laboratory Testing

A number of laboratory tests were performed to characterize the quality of the shotcrete cover. Six shotcrete panels (1 m by 1 m by 150 mm) were prepared in the field for laboratory testing. Panels 4 and 5 were composed of the tailings mix; the others were shot from various batches of the primary mix.

Compressive strength tests were performed on cylinders 150 mm in diameter and 300 mm in length cored from the test panels at various stages of curing. The results of these tests are given in table 3 and illustrated in figure 2.

Table 3. Compressive strength of shotcrete (MPa).

	Age of cylinders			
	28 days	100 days	200 days	400 days
Panel 1	16.3	19.5	27.1	33.2
Panel 2	7.1	9.4	10.4	24.2
Panel 3	8.1	11.6	13.7	29.0
Panel 4 (tailings)	10.9	16.2	16.6	22.0
Panel 5 (tailings)	13.1	21.0	32.2	33.1
Panel 6	7.9	12.0	11.5	27.2

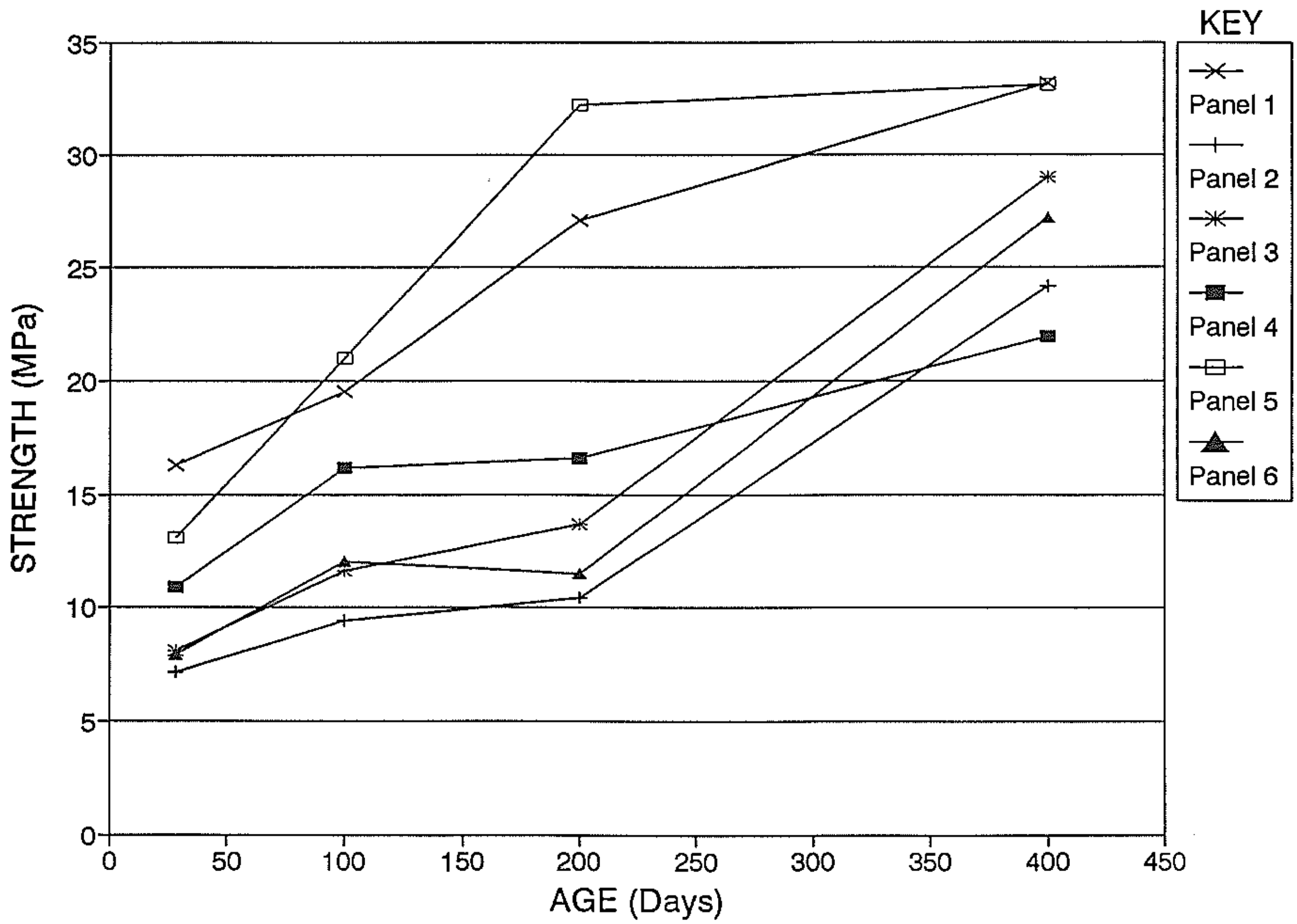

Figure 2. Compressive strength of shotcrete.

As a surface sealant, high-strength shotcrete is not required as long as it impedes infiltration of water and oxygen. The design objective was to achieve 15 to 20 MPa in compressive strength. After 400 days all of the panels achieved strength greater than the design objective. The strength gain was generally low over the first 200 days, during the winter period, but increased in the following 200 days during the warmer summer period. While all of the panels achieved the design objective for compressive strength, the values at 400 days range from 22.0 to 33.1 MPa. The inclusion of a superplasticizer would reduce this variability in the quality of the mix, but would increase the cost.

Concrete is typically a brittle material, exhibiting very low tensile strengths. Therefore, unreinforced concrete will tend to crack and separate following small deflections. Because the shotcrete material is designed for use as a surface sealant on a waste rock dump, the hardened concrete will require ductility to withstand local settlement within the waste slope. To evaluate the ductility of the test panels, toughness index tests were performed in accordance with ASTM C1018, Standard Test for Flexural Toughness and First-Crack Strength of Fiber Reinforced Concrete (Using Beam with Third Point Loading). Beams (100 mm by 100 mm by 350 mm) were cut from the shotcrete panels for flexural testing at 100 days' cure. Toughness of the shotcrete is defined as the total energy absorbed prior to complete separation of the specimen. This energy can be measured by calculating the area under the load deflection curve in flexure. The toughness in plain concrete is quite low and failure of the specimen usually occurs when the first crack develops. When fibers are present, the cracks cannot extend without stretching or debonding the fibers. As a result, considerable additional energy is required before complete fracture of the material occurs. The toughness index is defined as the ratio of the absorbed energy at various crack widths as compared to the absorbed energy when the first crack occurs. The results of the flexural tests (table 4) are variable, but the values are generally lower than the desired toughness indices of $I_5>3$ and $I_{10}>6$. These low values are not unexpected since a low fiber content (4 kg/m^3) was used to reduce the cost of the product. The field performance will be monitored to evaluate if this fiber content is adequate for this application.

Monitoring Program

No movement of the shotcrete cap was detected when the survey markers were remeasured in March 1993. A visual assessment was carried out in September 1993, and the overall durability performance of the cap was good. There was no evidence of major cracking or movement in the cap. The shotcrete did not appear to have suffered any frost damage or erosion. Some minor cracks were observed in two small areas where the shotcrete was thinner than the 75-mm standard depth. Iron staining was observed on these areas as a result of water flow from the waste rock dump through the shotcrete panel. The source of this flow is not certain, but it would appear to be lateral movement of water through the dump. The dump material is composed of a high percentage of fine particles and therefore retains moisture near the surface. Some plastic shrinkage cracks were observed in the shotcrete immediately after application. The primary cause of these cracks was the high rate of evaporation before initial set. In November 1992, cores were taken through a number of these cracks; some were found to extend through the cap, and others terminated approximately halfway through the cap. After 1 yr of exposure, these cracks did not appear to have expanded.

Cost of Shotcrete Cover

A major consideration in the design of the testing program was cost. Table 5 provides a breakdown of the cost of the project. It is apparent that the transportation of aggregate to the mine site is a substantial cost of the cover. If a local aggregate source, such as coarse tailing, were available, the unit cost per square meter of cover could be less than Cdn $12.

Table 4. Toughness tests of shotcrete at 100 days' cure.

	Primary mix	Tailings mix
Flexural strength MPa	1.5 - 2.0	2.9 - 3.1
Ductility:		
Toughness index I_5	1.6 - 2.7	1.4
Toughness index I_{10}	2.7 - 5	2.2 - 2.5

Table 5. Cost breakdown of shotcrete application.

	Cdn \$/m^2
Cement	1.28
Fibers	1.88
Fly ash	1.40
Aggregate (includes transportation)	7.10
Labor	3.30
Equipment	3.50
Total	18.46

Conclusions

This study indicates that shotcrete dry covers can be a viable option for sealing prepared waste rock dumps. Prior to shotcrete application, the surface of the dump must be stabilized through resloping and surface compaction. The application using a robotic spray boom resulted in high productivity and therefore contributed to a low application cost. A major proportion of the cost involved the importation of aggregate. The use of a local aggregate source such as mine tailings would make this option more cost effective when compared to other types of covers. The shotcrete material exhibited good compressive strength and moderate ductility. One year after application the cover was intact and functioning well.

This study did not evaluate the effectiveness of the cover in restricting acid generation in a waste rock pile. It is recommended that this cover technology be applied in a controlled field trial on a designed waste rock test pile to evaluate its effectiveness in restricting the access of oxygen and surface water infiltration to reactive waste rock.

Literature Cited

BC Acid Mine Drainage Task Force. 1989. Draft acid rock drainage technical guide. Prepared by Steffen Robertson Kirsten (BC) Inc. in association with Norecol Environmental Consultants and Gormely Process Engineering.

C.E. Jones and Associates Ltd. 1992. Decommissioning plan prepared for Westmin Resources Limited, Myra Falls Operations, Vancouver, BC.

Gerencher, E.H., D.E. Konasewich, J.Y. Wong, and R. van Dyk. 1991. The use of mine tailings in concrete surface covers to control acid mine drainage in waste rock dumps. p. 69-84. In Second International Conference on the Abatement of Acidic Drainage, Volume 4. (Montreal, PQ, September 16-18, 1991).

Langley, W.S. and D. Dibble. 1990. Field trials of shotcreting polypropylene fiber-reinforced high-volume fly ash (ASTM Class F) concrete. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Malhotra, V.M. 1991. Fiber-reinforced high-volume fly ash shotcrete for controlling aggressive leachates from exposed rock surfaces and mine tailings. p. 505-514. In Second International Conference on the Abatement of Acidic Drainage, Volume 1. (Montreal, PQ, September 16-18, 1991).

Malhotra, V.M., G.G. Carette, and A. Bilodeau. 1990. Fiber-reinforced high-volume fly ash shotcrete for controlling aggressive leachates from exposed rock surfaces and mine tailings. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Morgan, D.R. and N. McAskill. 1990. Evaluation of polypropylene fiber-reinforced high-volume fly ash shotcrete. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Seabrook, P.T. 1992. Shotcrete as an economical coating for waste piles. Paper presented at the Waste Management in the Cement Manufacturing Process Conference, Calgary, AB.