Cementitious Sealant Materials for ARD Control

by

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SHOTCRETE APPLICATION OF CEMENTITIOUS SEALANT MATERIALS FOR ACID ROCK DRAINAGE CONTROL

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SUMMARY

This report describes the testing program to incorporate waste mine tailings in a shotcrete mix for application on waste rock dumps to control acid mine drainage (AMD).

Initial laboratory trial mixes were performed to maximize the usage of waste materials. Testing has shown that mixtures incorporating up to 100% of mine tailings as aggregate can be solidified into homogenous matrices. Ductility in the structure, to withstand local settlement, was achieved using polypropylene fibres as reinforcement in the mixes. Due to the low water / cement ratios required to achieve the minimum design compressive strength, additives were included in the design to make the mixtures more workable. Fly ash was incorporated in the mixtures to lower the material cost. It was found that the minimum cementitious content in the mixes should not be lower than 25 %.

Based on testing of the laboratory trial mixtures, proportions of materials were modified for the shotcrete test panels. Five mixtures were shot using the wet mix shotcrete process. The designed mixtures were found to be pumpable and adhered to vertical surfaces. Testing of the panels showed that mixtures with quantities of mine tailings in excess of 40% as aggregate, will adversely affect the compressive strength of the material.

This study has shown that a fibre reinforced solidified cementitious cover can be applied to sloping waste rock surfaces using shotcreting methods. It is therefore recommended that this material be tested in a pilot scale model to evaluate the effectiveness of a cementitious surface sealant to restrict acid generation with the rock pile.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1

2.0 MIX DESIGN 2

2.1 Materials 2

2.1.1 Aggregates 3
2.1.2 Cementitious Materials 3
2.1.3 Fibres 4
2.1.4 Additives 4

3.0 LABORATORY TRIAL MIXES 4

3.1 Mix Proportions 4
3.2 Mix Procedure 5
3.3 Test Results of Laboratory Mixtures 5

3.3.1 Properties of Fresh Concrete 5
3.3.2 Compressive Strength 6
3.3.3 Toughness 6

4.0 SHOTCRETE TEST PANELS 7

4.1 Equipment 7
4.2 Application 8
4.3 Test Results of Shotcrete Panels 8

4.3.1 Compressive Strength 9
4.3.2 Flexural Toughness 9
4.3.3 Air Content 9
4.3.4 Absorption After Boiling and Permeable Voids 9
4.3.5 Permeability 9

5.0 DISCUSSION 10

5.1 Compressive Strength 10
5.2 Flexural Properties 12
5.3 Permeability 12
5.4 Durability 13

Page

6.0 COST 14

7.0 CONCLUSIONS AND RECOMMENDATIONS 16

8.0 REFERENCES 18

TABLES

FIGURES

APPENDIX A MATERIALS CHARACTERIZATION

APPENDIX B COMPRESSIVE STRENGTH TESTS

APPENDIX C FLEXURAL TOUGHNESS TESTS

1.0 INTRODUCTION

Recent studies by Northwest Geochem[1] evaluated the efficacy of solidified mixtures containing cement, water treatment sludge, mine tailings, and sand for use both as a surface sealant and a grouting matrix for the control of acid rock drainage at the Westmin Myra Falls site. Laboratory results indicated that the solidified cementitious mixtures developed can achieve good compressive strengths, workability, and durability. Field scale trials have further evaluated the durability and weathering of the solidified mixtures and demonstrated that the metal levels in the sealant surface runoff do not exceed effluent criteria. However, the mixtures to date have been designed as a placed cement product. Field trials indicate that this method of application has serious drawbacks when used to cover sloping rock faces due to the thickness of the application, difficulty in access, and large areas to be covered.

An alternative application technique to the poured approach is using shotcrete which can place concrete on steep rock faces and sloping waste rock dumps at controlled thicknesses. Shotcrete is mortar or concrete shot into place by means of compressed air. The shotcrete has to have a relatively dry consistency so that the material can support itself in any position; at the same time, the mix has to be wet enough to obtain compaction and adhere to the surface. The high velocity with which the concrete is shot also gives shotcrete a high bond strength.

The purpose of this study is to determine how to optimize the use of mine wastes such as coarse tailings in a shotcrete mix which can be applied to vertical or sloped rock faces.

The research program consisted of the following:

- Design of the shotcrete mix to maximize the use of mine tailings.

- Trial mixes to investigate the effects of the addition of waste materials, admixtures, and fibres to the shotcrete and to evaluate material properties.

- A pilot scale test in which test panels of the shotcrete were shot.

- Testing of the shotcrete panels in accordance to established ASTM and CSA procedures.

2.0 MIX DESIGN

Because of the potentially large areas at the mine site to be covered by the solidified mine tailings, cost was a major consideration in the mix design. The use of mine tailings in the mix was maximized because of the high cost of importing materials to the site. Other important factors incorporated into the design of the cementitious mixtures were as follows:

- The mix must have good workability so that it can be easily pumped.
- The solidified mix must be durable.
- A reasonable compressive strength should be achieved but a high compressive strength is not critical.
- The hardened shotcrete should exhibit good ductility in order to withstand any local settlement in the rock slope.

2.1 Materials

The characterization test results of the materials used in this research program are listed in Appendix A

2.1.1 Aggregates

In conventional shotcrete mixes the aggregate should comply with the requirements of ASTM C33 for grading and quality of aggregates for use in concrete. Gradation No. 1 from ASTM C33 is plotted in Figure 1 along with the gradations for concrete, sand, gravel, tailings, and a blend of sand and gravel. Westmin coarse tailings consist primarily of fine grained sand sizes while the fine tailings are mostly of silt size. It has been shown that gradations consisting of finer materials than a fine grained sand result in solidified materials with a high drying shrinkage, therefore, it was decided to use only the coarse tailings in this testing program.

2.1.2 Cementitious Materials

The cementitious materials used in this program were portland cement and fly ash. Type 10 portland cement was used.

Recent studies [2,3,4] have shown that high volumes of fly ash can be used successfully in shotcrete applications. The advantages of incorporating fly ash into the cementitious are:

- lower cost (fly ash is a waste by-product from thermal power generation)
- lower heat of hydration in the mix thus reducing the potential for cracking.

A Class F fly ash was used in this study. The composition is shown in Appendix A.

2.1.3 Fibres

A major concern in the placement of solidified cementitious materials over a large area is the potential for cracking due to local settlement and shrinkage during curing. The addition of polypropylene synthetic fibres to the mix will inhibit the cracking and increase the "toughness" of the solidified material.

A 38 mm polypropylene mesh type fibre from Fibermesh was used at a dosage rate of 5 kg/m^3. The fibre works without affecting the chemical hydration of the cement. Its action is purely mechanical and should be compatible with all mixes and admixtures. It cannot rust, is non corrosive and is alkali resistant.

2.1.4 Additives

Freeze thaw resistance in concrete is highly dependent on the amount of entrained air in the mix. The optimum air content in most mixes ranges from approximately 5% to 10%. An air entrainment additive, DARAVAIR, was used at a dosage of 200 ml per 100 kg to increase the air content to the optimum range.

The water to cementitious ratio was kept constant in this study. The water cement ratio used, 0.38, is low resulting in a stiff mix which may be hard to pump. To improve the workability of the mix a superplasticizer, DARACHEM, was used at a dosage rate of 450 ml per 100 kg.

3.0 LABORATORY TRIAL MIXES

3.1 Mix Proportions

Preliminary trial mixes were performed in the laboratory in order assess the workability and mechanical properties of concrete with various tailing content. The five mixes chosen for laboratory testing are listed in Table 1. The tailing contents in these mixes varied between 40% to 100% of the total aggregate. The gradations of the blended aggregate in the different mixes are shown in Figure 2. The water/cementitious materials (cement+flyash) ratio was kept constant at 0.38 for all the mixes.

3.2 Mix Procedure

Batching of the trial mixes was carried out using a rotating drum mixer. Each mix was approximately 0.042 m^3 in volume. The sequence of mixing was as follows:

1. Proportion the materials by weight
2. Place sand and gravel in mixer
3. Place tailings in mixer
4. Add 1/3 water
5. Add fly ash and cement
6. Add remaining water
7. Add admixtures
8. Measure air & slump
9. Add fibres
10. Measure air & slump again
11. Cast test specimens

The specimens were consolidated on a vibrating table in order to simulate the placement using shotcrete.

3.3 Test Results of Laboratory Mixtures

3.3.1 Properties of Fresh Concrete

No major problems were encountered during mixing of the five test mixtures. The fibres were well dispersed into the cement matrix and did not exhibit any clustering. Mix C was the only mixture that exhibited any bleeding after consolidation. Properties of the fresh concrete are summarized in Table 2.

3.3.2 Compressive Strength

Cylinders were prepared for compressive strength testing at 7, 28, and 91 days. The cylinder dimensions were 100 mm in diameter and 200 mm in length. The results are tabulated in Table 3. Mixes A, B, D, and E all had 28 day strengths greater than 10 MPa. Mix E contained less cementitious materials and thus exhibited lower strength. Due to the addition of fly ash, there was a strength gain at 91 days. The compressive strengths obtained in these mixes were reasonably good considering the high usage of very fine aggregates. The solidified material is to be used as a surface sealant and thus high compressive strength is not critical. The complete testing details are shown in Appendix B.

3.3.3 Toughness

Toughness index tests were performed in accordance to ASTM C1018, "Standard Test for Flexural Toughness and First-Crack Strength of Fibre-Reinforced Concrete (Using Beam with Third Point Loading)". This test was carried out on an Instron Dynamic Material Testing System (Model 1333). The purpose of this test is to determine if the mixtures are classified as elastic-plastic materials. The definition of toughness indices is described schematically in Figure 3.

The dimensions of the test beams were 100 mm x 100 mm x 350 mm. The span length used for third point loading was 300 mm. The results of the toughness tests are shown in Table 4 along with the flexural strengths. Although the flexural strengths are low, it can be seen from the high toughness indices that the materials are considered to be elastic-plastic. The load deflection curves for these tests are shown in Appendix C. Note that after cracking has occurred, the load is still sustained as the beam continues to deflect. The fibres give the structure ductility as compared with plain concrete where the load will drop to zero. Figure 4 shows a typical test specimen after a crack has developed.

4.0 SHOTCRETE TEST PANELS

A pilot scale test was performed in which test panels were produced using shotcrete containing various tailing content. This scale of testing is important to establish that the properties of the shotcrete are consistent with the mixes placed by conventional concrete consolidation methods.

The shotcrete test panels were shot on the premises of Terracrete Systems Ltd. on December 7, 1990.

4.1 Equipment

The shotcrete was applied using the wet mix process. This process consists of the following steps:

1. All the materials are thoroughly mixed.
2. The concrete is placed into the chamber of the delivery equipment.
3. The mixture is metered into the delivery hose and moved by displacement to a nozzle. A schematic of the pumping equipment is shown in Figure 5.
4. Additional air is injected at the nozzle to increase velocity and improve gunning pattern.
5. The concrete is jetted from the nozzle at high velocity onto the surface to be shotcreted.

Equipment:

- wet mix nozzle (see Figure 6)
- diesel powered Thompson double piston shotcrete pump (see Figure 7)
- 2" ID delivery hose
- 375 CFM air compressor
- rotary drum mixer

curing. In addition, the mixture with the lowest cementitious content experienced bleeding during consolidation indicating a requirement for a larger quantity of cementitious material.

The effect of the cement to fly ash ratio on compressive strength of the cementitious mixtures was also evaluated. Figure 16 and 17 show that a higher cement to fly ash ratio resulted in higher strength gain even at 91 days of curing. However, this effect may be offset by a longer curing period.

5.2 Flexural Properties

Concrete is a brittle material with a very low tensile strength. Unreinforced concrete will tend to crack and separate following a small deflection. However, the shotcrete material developed in this study is to be used as a surface sealant on a waste rock dump; therefore, the hardened concrete will require ductility to withstand local settlement within the rock slope. In most shotcrete designs the desired toughness indices are usually $I_5>3$ and $I_{10}>6$ (see Figure 3 for a definition of these terms). The shotcrete mixtures were therefore designed to match or exceed these indices. The flexural properties of all the mixtures in both the lab trials and the shotcrete panels showed good ductility. Tables 4, 7 and 8 showed that the majority of samples tested had toughness indices exceeding the desired values. Lab mixture E, which contained the highest cement content together with 100% mine tailings as aggregate, had toughness indices lower than the design values. It is uncertain whether the lower toughness index for this sample was due to the higher cement content or the large quantity of fine-grained aggregate in the sample. The addition of polypropylene fibers in the mixtures appears to restrict the propagation of cracks by improving the tensile strength of the composite material.

5.3 Permeability

A correlation between absorption and permeability as an index of shotcrete quality in terms of strength has been reported[5]. Because of the fine-grained nature of the mine tailings used as aggregate in the study, both the absorption and the volume of permeable voids was high indicating that the shotcrete produced would be considered to be of marginal quality. Testing showed that as the quantity of sand and gravel in the cementitious mixtures was increased the absorption and volume of permeable voids decreased. Permeability testing, however, indicated that all mixtures had low permeabilities to water in the order of 10^{-10} m/s. Air void examination of the hardened cementitious mixtures showed air contents of less than 5%, suggesting that the elevated absorption values are due to the high surface area of the fine-grained mine tailings and do not represent void spaces which would contribute to increased permeability of the sample. In addition, microscopic examination of the cementitious structure showed a well distributed air void system without interconnecting pores, entrapped air and micro-cracks. During field spraying of the shotcrete mixtures it was found that an overdose of air entrainment additive was required to achieve the desired air void content following shotcreting. It is unclear, at this time, how the high absorption values measured will affect the long-term durability of the cementitious mixtures.

5.4 Durability

Although freeze-thaw resistance was not evaluated in this study, air void examination showed that the shotcrete mixtures developed may have good freeze-thaw resistance because of the air contents measured and the shape of the air voids.

Analysis of mine tailings used as aggregate in this study indicated abnormally high sulfate content in the order of 1.5%. The Portland Cement Association recommends a maximum permissible sulfate content of 0.5% to avoid sulfate attack of the concrete structure. Subsequent discussions with Westmin Mines personnel indicated that tailings with a more suitable sulfate content is available at the mine site in sufficient quantities. The use of sulfate resistant cement may also alleviate concerns regarding long term durability of the cementitious mixtures.

6.0 COST

The chief advantage of using the shotcrete mixes developed in this study is that the aggregate content may be obtained from the site, thereby avoiding the high cost of transporting aggregate from Campbell River.

The material costs for this study are:

1. Flyash - transported to Westmin		$90. / metric tonne
2. Type 10 cement - transported to Westmin		$140. / metric tonne
3. Polypropylene fibres	(.9kg / bag)	$6.50 / bag
4. Air entrainment agent		$1.90 / litre
5. Superplasticizer		$3.19 / litre

The total materials costs assuming the aggregate can be obtained from the site without cost are:

Material	quantity / m^3	cost / m^3	cost / m^2
fly ash	288 kg	$25.92	$2.59
cement	192 kg	$26.88	$2.69
fibres	5 kg	$36.11	$3.61
air entrainment	0.9 litre	$1.82	$0.18
superplactizer	2.16 litre	$6.89	$0.69

The total material cost for a cubic metre of shotcrete is $97. Assuming that the average thickness of the shotcrete is 100mm, the total material cost for a square metre of shotcrete is $9.70.

The cost for application of the shotcrete onto the rock slope will depend on several factors including the condition of the rock slope, and the type of equipment used. Manual application, with an operator suspended from the top of a rock slope will result in the lowest production rate. The application rate will increase if the operator is shooting from an aerial lift device. Terracrete Systems is now developing a robotic shotcrete unit which may further increase the application rate.

7.0 CONCLUSIONS AND RECOMMENDATIONS

A study was conducted to develop a shotcrete mixture incorporating mine tailings which can be used as a surface sealant on sloping waste rock surfaces to control acid rock drainage. Five cementitious mixes were prepared and tested in the laboratory to optimize the use of polypropylene fibers, fly ash and mine tailings. Based on testing of the laboratory mixtures, proportions of materials were modified for the shotcrete test panels. The panels were shot and tested in accordance to established ASTM and CSA procedures. The field results showed that the mixtures can be placed onto vertical surfaces using the wet-mix shotcrete method. Testing indicated that:

- The mine tailings could be effectively incorporated into a cementitious mixture and the mixtures were easily workable, even with the low water to cement ratio used in this study.

- Mixtures with a high volume of fly ash attained 91 day strengths as high as 26 MPa.

- The minimum cementitious material content required to produce mixtures with acceptable physical properties was determined to be 25% of the total weight of the mixture.

- The laboratory mixtures show that up to 100% mine tailings, as aggregate, can be incorporated into the mixture without adversely affecting the compressive strength of the solidified mixtures. However, testing of the shotcrete panels indicated that quantities of mine tailings in excess of 40%, as aggregate, will adversely affect the compressive strength of the solidified cementitious mixture.

- An overdose of air entrainment additive was required to achieve the desired air void content following shotcreting.

- Water permeability of all the shotcrete mixtures was very low in the order of 10^{-10} m/s.

- The addition of polypropylene fibers contributed to ductility of the solidified materials.

- The toughness indices indicate that the solidified cementitious materials will likely resist major cracking as a result of local settlement in an environment such as a waste rock dump.

Further work is recommended to enable field testing of shotcreted cementitious mixtures for use as a surface sealant to restrict acid generation. The use of covers (either layered, synthetic or solidified) to restrict acid generation and control acid rock drainage has not been fully evaluated under field conditions. This study has shown that a fiber reinforced solidified cementitious cover can be applied using shotcreting methods to sloping waste rock surfaces. It is therefore, recommended that this material be used as a surface sealant in a pilot scale model to evaluate the effectiveness of the cover to restrict acid generation within a waste rock pile. The pilot scale system would be modelled after the waste rock dump conditions at Westmin's Myra Falls operations. Such a testing system would evaluate material properties such as durability and weatherability as well as leachability of the solidified cover. In addition, acid mine drainage parameters would be monitored to determine the effectiveness of the cover in restricting acid generation within the waste rock pile. It is important to initiate pilot scale testing as soon as possible to ensure data collection over a suitably long period of time.

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