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An Evaluation of Binder Alternatives For Hydraulic Mill Tailings Backfill

Interim Report

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An Evaluation of Binder Alternatives For Hydraulic Mill Tailings Backfill

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ABSTRACT

Underground mining often requires that the void left from extracting the ore be filled with a backfill material. This material can be many things but the most common fill in use today is mill tailings. In many mining applications these mill tailing backfills need to be consolidated with some sort of binding material. At the present time, backfills are most commonly consolidated with Portland cement. This consolidation of mine backfill can be an expensive procedure due to the cost of the binder. In many cases the binder cost alone is equal to the cost of preparing, transporting and placing the fill in the mined out stopes underground.

This paper examines five of the most attractive binder alternatives used to consolidate mill tailings backfill in place of Portland cement. An optimum binder was selected and an underground trial was completed to confirm the laboratory test results. Using this optimum binder an economic evaluation was made comparing the cost of using the binder alternative versus Portland cement in a typical primary blast hole stope underground.

Recommendations are made as to how an operating mine may want to test this optimum binder in their own backfill.

ACKNOWLEDGMENTS

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SUMMARY

The most common underground backfill in use in Canadian mines today remains hydraulic mill tailings. In mines where consolidation of these tailings is required Portland cement is the most common binder employed. This consolidation of mine backfill is a major operating cost and can be potentially improved by replacing the Portland cement with a less expensive binder alternative.

Five binder alternatives were tested:

- Type-C Fly Ash
- Slag Cement "A"
- Slag Cement "A" Activated With Lime
- Slag Cement "B"
- Slag Cement "B" Activated With Lime

These five binders were selected for their availability and lower unit costs. Slag cement "A" appeared to be the most attractive and was tested further.

Slag cement does not only reduce the cost of a mine's consolidated backfill but can also improve the fill quality. An example of this is shown when mill tailings from Falconbridge's Strathcona mill are consolidated with 5% Slag cement rather than 5% Portland cement. The savings in an example like this can be as high as $3.41 per ton of fill poured or a 64% binder cost savings over the same fill consolidated with Portland cement. The fill that is consolidated with the slag can be as strong as the fill with the Portland cement after only four days and up to 350% stronger after one month of curing.

In an attempt to gain confidence in the laboratory findings an underground stope trial was run using Slag "A" as the binding agent instead of Portland cement. The operators and technical personnel found this fill to be of noticeably higher quality.

Lime additions of between one to three percent resulted in uncharacteristicly high early strength in the backfills consolidated with slag cement. Lime addition rates are by dry weight of the binder.

It is not clear why the use of slag cement to replace Portland Cement in hydraulic fill results in a higher ultimate strength. It is suspected that either residual chemistry in the fill and/or fineness of grind of the Slag cement are contributing factors. Due to this uncertainty it is recommended that Slag cement be tested as a binder alternative with each different backfill before attempting to use it mine wide.

Slag "A", which was found to be most effective in this study and is available for most mines in Ontario and possibly western Quebec. Some of the other binder alternatives tested, such as Type-C Fly Ash, may be more readily available in other parts of Canada and therefore may be more attractive as a low cost binder alternative for Portland cement.

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AUTHOR BIOGRAPHIES

Philip Hopkins	-	Philip graduated from Queens University, B.Sc. Mining Engineering, 1982, and is presently employed as a Project Engineer-Backfill, responsible for the backfilling Research & Technology operations within Falconbridge's Sudbury Operations. Prior to this he worked with Falconbridge in their Equipment Technology Division and with Cominco Limited (Yellowknife) as a Planning Engineer, Maintenance Foreman and Services and Production Shift Supervisor.
Michel Beaudry	-	Michel was born in Verner, Ontario and joined Falconbridge Limited in 1969. He worked as a driller and stope leader until 1979 when he joined the Industrial Engineering group. Since 1984 Michel has worked as an Engineering Assistant in the backfill Technology Department.

An Evaluation of Binder Alternatives For Hydraulic Mill Tailings Backfill

Introduction

Over the past decades waste materials have been sent back underground, in one form or another, to fill the void left by mining. This backfill material has varied in composition from crushed or broken aggregate to finely ground mill tailings and has been delivered to underground sites in the form of slurries, solids and, more recently, pastes. In addition, the method of transport has also varied from boreholes and pipes, waste skips and LHD equipment to waste passes and conveyor belts (and many combinations of the above).

Although crushed rock and dense fill systems are becoming popular, the most common mine backfilling method used in Canada is conventional hydraulic mill tailings. This finely ground mill waste material is sent underground as a slurry into an empty stope where the excess water is drained away and the material is left behind as fill. Depending on the requirements for this backfill, a binder or cementing agent may be desired. Once again, various different cementing agents are in use today such as Portland Cement, Blast Furnace Slag Cement and Fly Ash. The most common binding agent is Portland Cement. This paper addresses less expensive alternatives to Portland cement and improvements possible to their effectiveness when used as a binder for hydraulic fill.

Various binding agents have been tested in the past to reduce backfilling costs but have required that the mine either accept a loss in early strength development or final fill quality. In these cases scheduling or safety concerns often arose. It became evident that a less expensive binding agent was required that would not sacrifice fill quality.

<u>Experiment Outline</u>

The majority of the laboratory and field test work was centered around the following four fundamental backfill binder alternatives:

1 - Type-10 Normal Portland cement
2 - Iron ore blast furnace slag from Stelco Limited
3 - Iron ore blast furnace slag from Algoma Steel Limited
4 - A mix of Detroit Type-C fly ash and Type-10 cement

Alternative binders such as Anhydrites, Silica Fumes, Monolithic packing materials and Type-F Fly Ash were reviewed but were not evaluated in detail for reasons such as: poor availability, handling difficulties, poor initial test results or costs.

Strathcona Mill classified tailings were used as the basis for all binder tests. The mineralogy and size distribution of this material is shown in Figures 1 and 2 respectively. Laboratory tests were completed under the following conditions:

* 68% Pulp density
* Curing humidity = 100%
* 1-56 day curing period with a 24 hour open air drying time prior to testing
* Samples tested were 3" x 6" undrained cylinders
* Binder addition levels of - 8:1 (tailings:binder) or 11.1%
- 16:1 " " or 5.9%
- 32:1 " " or 3.0%
* Unconfined uniaxial compressive strength testing

Lime addition was used as an activating agent with the slag cements to enhance early strength. A full range of lime addition rates were tested with only the most beneficial being presented in this paper.

Various combinations of Type-C Fly Ash and Portland Cement were tested. This paper presents only the most effective mix.

Mineral	%
Quartz	24
Feldspar	33
Pyroxene	22
Amphibole	12
Phyllosilicates	4
Epidote (other silicates)	3
Magnetite, Chromite, Ilmenite	1
Sulfides (mostly pyrrhotite)	1
Total %	100

FIGURE 1: Mineralogy of Strathcona Classified Mill Tailings

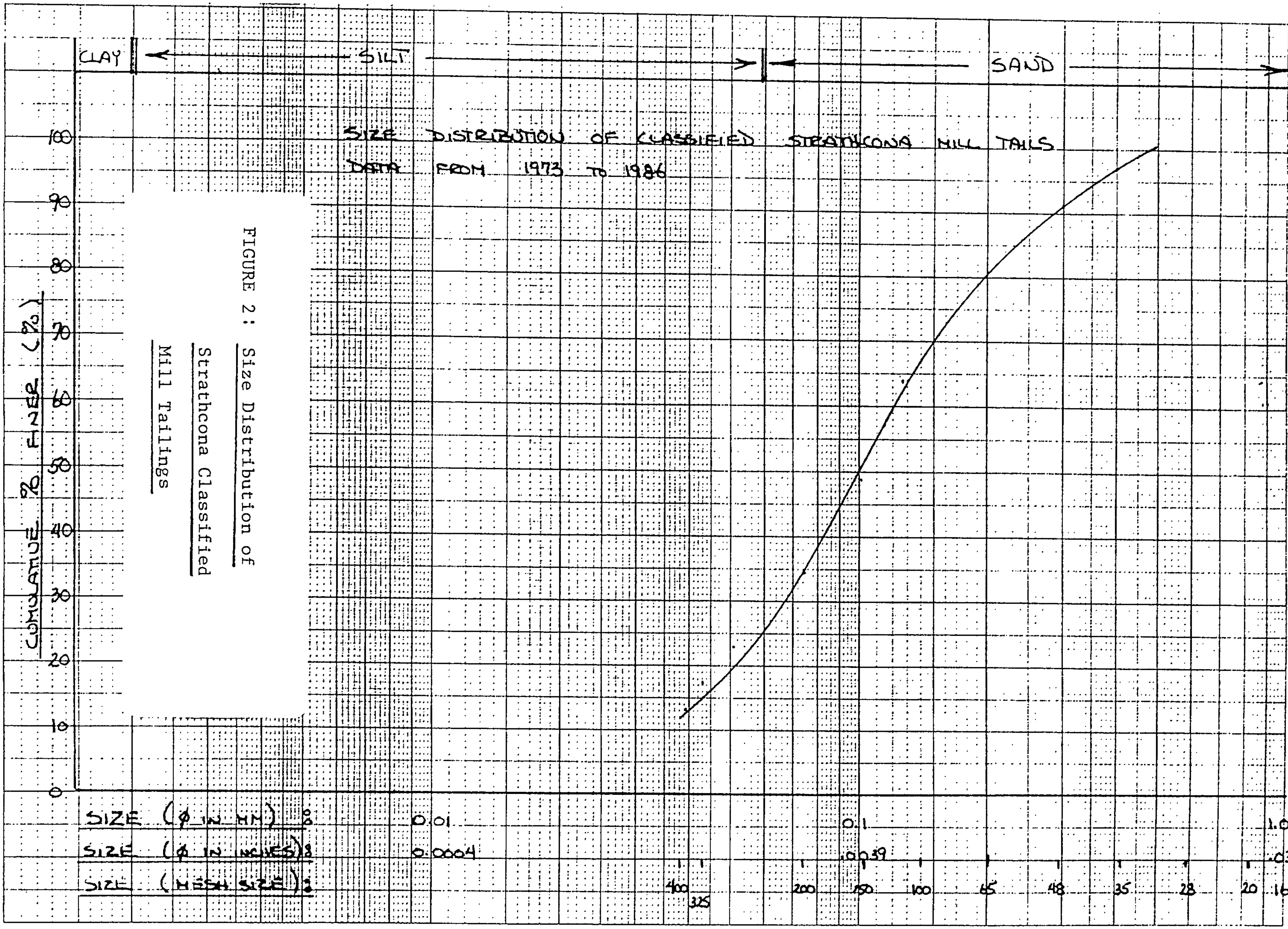


FIGURE 2: Size Distribution of Strathcona Classified Mill Tailings

Initial Laboratory Testing

The 28 day unconfined uniaxial compressive strength test results are shown in Figure 3. To evaluate the data in Figure 3, two aspects of consolidated backfill strength should be considered. These are, 1) the early strength obtained after four days and 2) the ultimate fill strength obtained after the fill has fully cured.

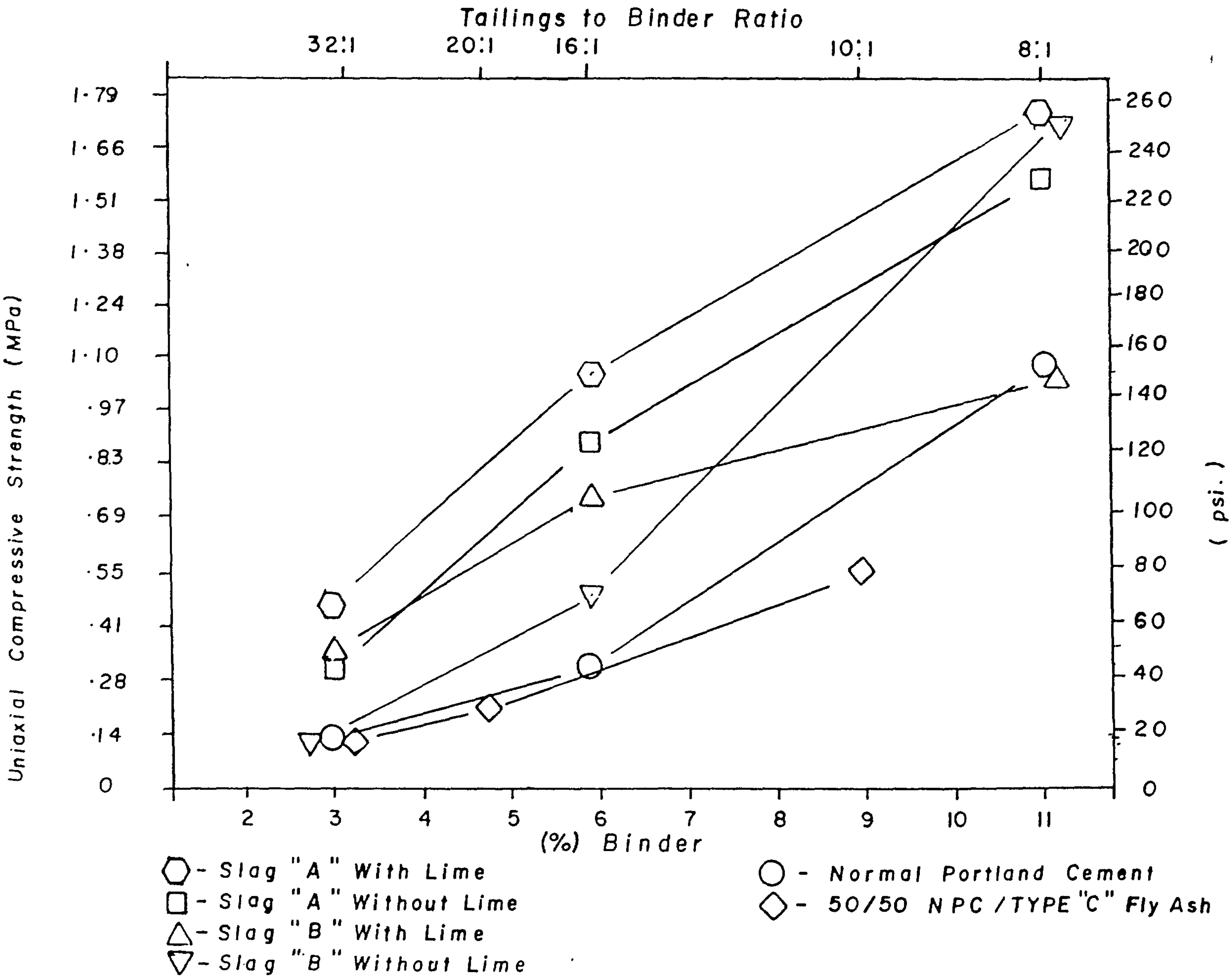
Short term backfill strength is important to those mines which need to fill a given area and then return quickly to this area with men and/or machines. This early strength is also important to mines that pour backfill plugs in the bottom of blasthole stopes. These plugs then retain the bulk of the stope fill. Early strength in this plug allows the mine to complete the remainder of the stope backfilling on a shorter schedule.

Final strength is often the basis for design of the composition of the consolidated backfill. It is the final fill quality that will allow a mine to efficiently mine next to a previously backfilled stope. High fill quality will minimize fill dilution and can improve local ground conditions in areas of high stress. These two points involving the effectiveness of consolidated mine backfills have been studied by many mining groups and companies around the world. This topic is out of the scope of this paper.

Slag "A" with lime proved to have the highest ultimate strength and was selected for further detailed lab tests. This work is described in the following section and addresses the early strength capabilities of Slag "A" with lime.

Various companies and research groups that have previously tested Portland cement alternatives were contacted and asked for their opinions on the different strength gains indicated in Figure 3. None were able to provide a definitive answer. One difficulty may be the low pulp density (68%) common in pouring backfill in comparison to the higher densities that exist in the concrete industry. It should be noted that there are very few "experts" in the area of backfill technology and only a limited amount of work has been done on replacements for Portland cement in hydraulic mill tailings backfill.

The Appendix lists some of the physical and chemical properties of the four binder alternatives tested. These properties may play an important role in the development of backfill strength.



COMPARISON OF VARIOUS BINDERS

Figure 3: Binder Altern-tive 28 Day Strengths

Follow-Up Laboratory Testing

Blast Furnace Slag "A" versus Type-10 Portland Cement

Blast Furnace Slag "A", a bi-product of steel production, appeared to be the most attractive binder alternative to Portland cement. In order to verify the initial data obtained and to confirm that activation of this slag cement was possible with minor additions of lime, detailed laboratory study was performed. The results of this work are shown in Figure 4.

Slag "A" had a higher ultimate strength in all three of the binder addition rates tested. In the cases of three and six percent binder addition this final strength was as high as three times that of Portland cement after one month and more than four times the strength after two months.

An early backfill strength that allows men and machines to work on the fill and allows bulk stopes to continue bulk pours, is an important consideration for consolidated fills. A fill strength build up rate equivalent to that obtained with Portland cement is achieved by slag "A" when 6% or greater binder is used. Approximately eight days are required when less than 6% binder is added. The effect of this eight day curing period would have to be considered by any user in conjunction with its effect on mine scheduling.

Additional data obtained from these tests is shown in Figure 5. This data will be used in the section on economic comparisons.

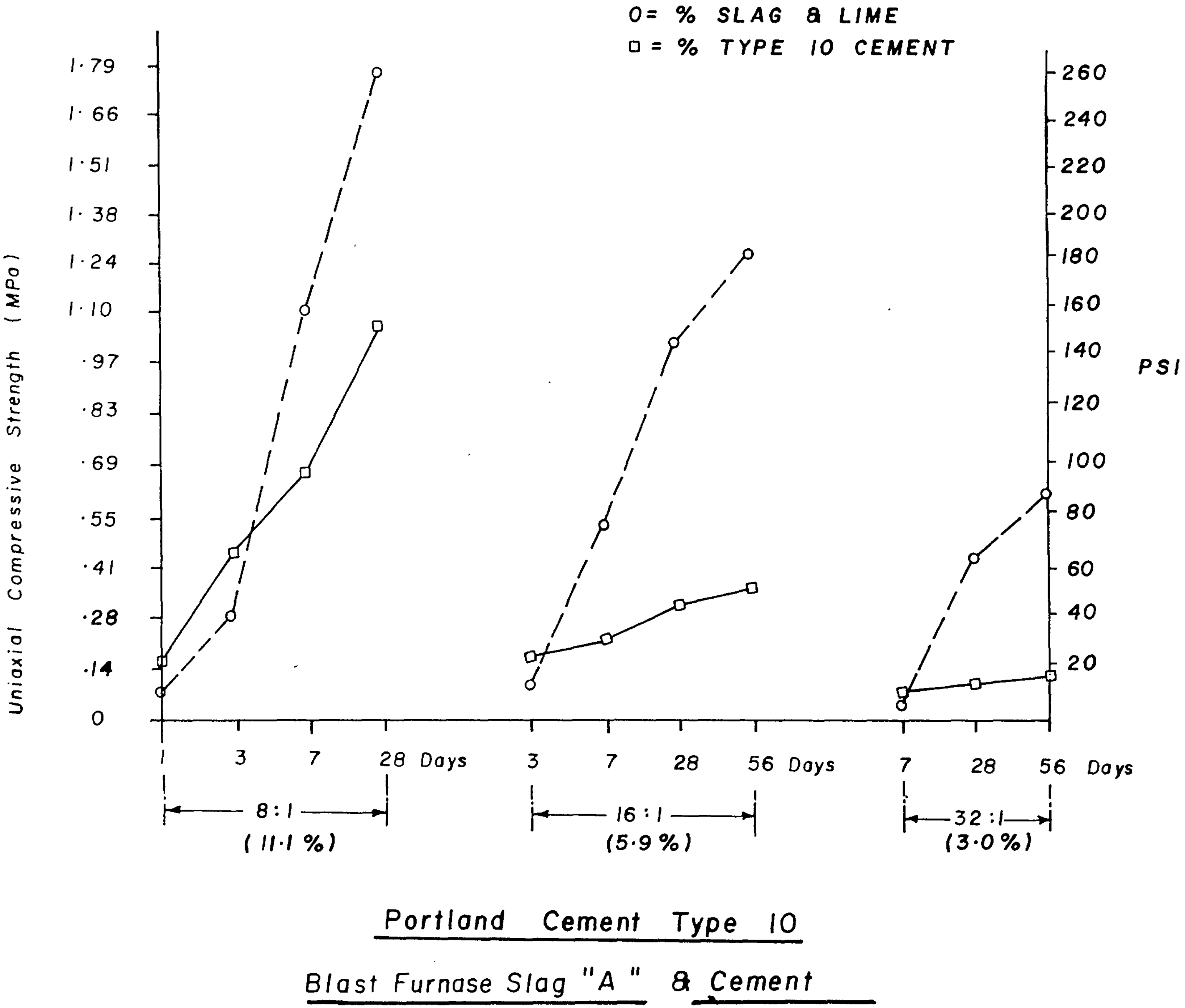
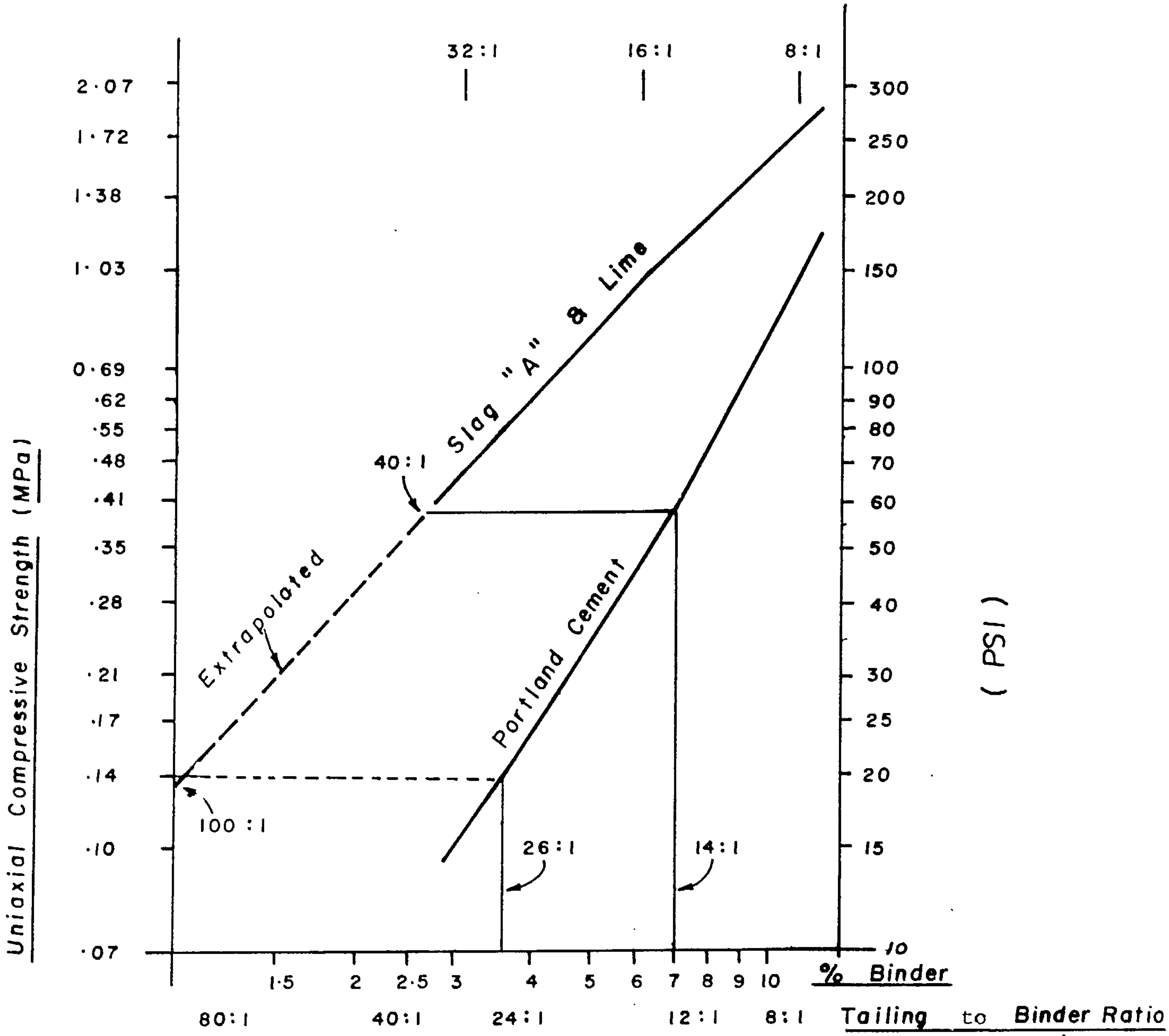


Figure 4: Comparison of Portland Cement Versus Slag "A"



28 Dav Results

Figure 5: Strength Curves for Portland Cement and Slag "A"

Underground Field Test

Laboratory tests are the most common method of comparing the various backfill designs. Because underground conditions vary from those in the lab a full scale field trial is mandatory to confirm that any improvements indicated from a lab study are obtained underground.

To evaluate Slag "A" as a binder alternative a typical cut and fill stope on the 2700 level of Falconbridge's Strathcona Mine was chosen for a field trial. This ore zone is steeply dipping (approximately 70 degrees), roughly 15 feet wide and 120 feet in strike length. Two layers of hydraulic fill were poured. Each layer contained a different binder addition rate. The first or bottom three feet was filled with backfill containing 3% (32:1 tailings:binder) Slag "A" and the top or final three feet was filled with 6% binder addition. The trial layout is shown below.

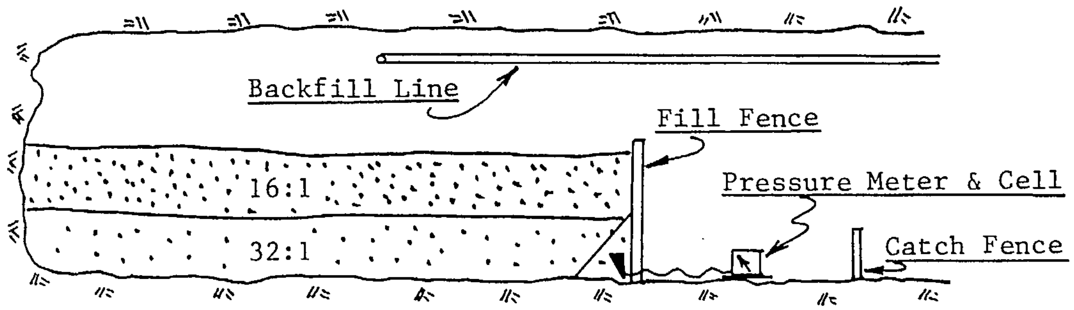


Figure 6: Underground Slag Cement Trial - Layout

The two layers were poured with one day between the pours. Each pour was observed by the mine operating personnel for their subjective comments. A pressure meter cell was installed at the bottom of the fill fence to monitor the hydraulic head resulting from hydraulic filling. A low measurement of pressure would indicate effective excess fill water drainage. Diamond drilling of this fill to obtain core samples was reviewed but considered to be too costly.

The pouring of both layers of the test fill was observed a mine captain, shift supervisor and the backfill technology engineer. No special design changes were made to the backfill plant on surface or to the stope to be filled underground, in order to complete this trial. During the first test pour (3% Slag) the mine Captain was able to walk on the fill within two feet of the backfill discharge point and commented, "I have not seen backfill of this quality in many years". After one month of curing technical personnel returned to the test site to extract a large test sample. This sample was extracted using hand tools.

A sample from the more highly consolidated top layer was to be taken. However, hand tools could not break away a reasonable sample of the fill and sampling efforts were discontinued.

The results from the pressure cell located at the base of the fill fence showed that there was no hydraulic pressure buildup during or after backfilling. This fact and the ability of men to walk directly beside the backfill pour point during the pour, something that is not common for our consolidated fill, indicated good fill drainage.

No underground design changes appear necessary in order to use slag "A" as a binder.

Availability of Binder Alternatives

Figure 7 shows where in Canada each of the four binder alternatives can be found.

Each of these binder alternatives are bi-products from other industries, and are most easily obtained in the specific areas where the primary industry is located. Type-C Fly Ash can be found wherever sub-bituminous coal is burned for electrical energy (Quebec, Ontario, and most of western Canada) and Slag cement is found in locations where waste slag from the iron refining process exists (Ontario).

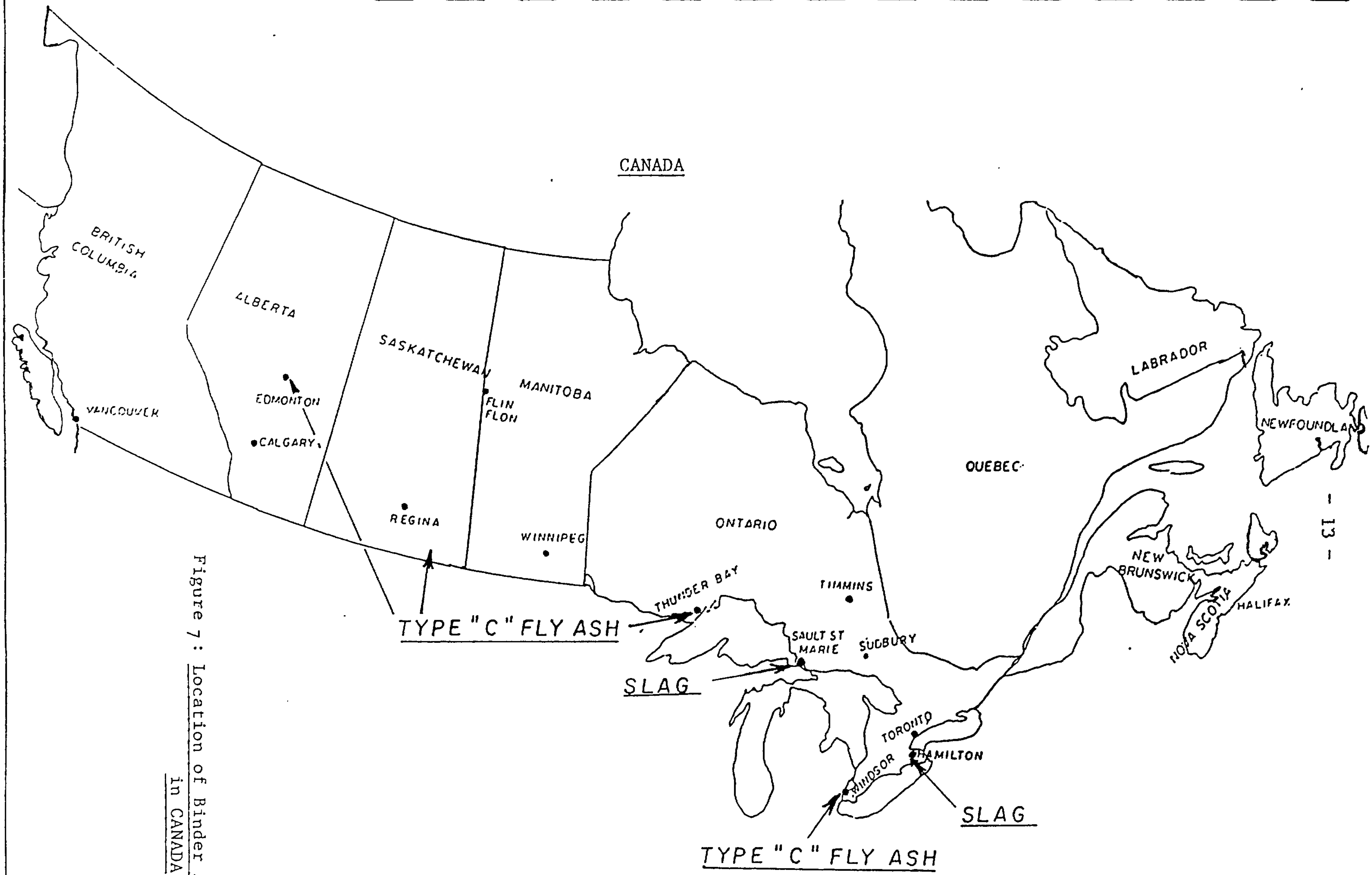


Figure 7: Location of Binder Alternatives in CANADA

Economic Comparison

Between Slag "A" and Portland Cement For a Blasthole Stope

The advantages of using Slag "A" as a binder alternative come from two sources:

1 - The money saved from using Slag "A" instead of the more expensive Portland cement and,

2 - Being able to use less Slag "A" per ton of backfill to achieve strength equivalent to Portland cement.

For economic comparison, the price used for each binder was:

Portland cement . . . . 105 $ / ton

Slag "A". . . . . 75 $ / ton

Note ** - These prices do not represent contract prices but are an approximate price for the northern Ontario region.

A typical blasthole stope at Falconbridge's Lockerby Mine in Sudbury was used (Figure 8) to make the economic comparison. This stope has dimensions 175' high, 36' wide and 50' deep and requires 2250 tons of consolidated 6.6% (14:1) fill as a plug. The remaining 13,500 tons of fill contain 4.8% (20:1) of binder and constitute the bulk of the pour. These are common consolidation ratios for a stope of this type that will encounter mining on both sides. Backfill consolidation is designed to minimize fill failure during the subsequent adjacent mining operations and thereby reduce the dilution.

Figure 9 presents the results of the economic comparisons. Three options are compared:

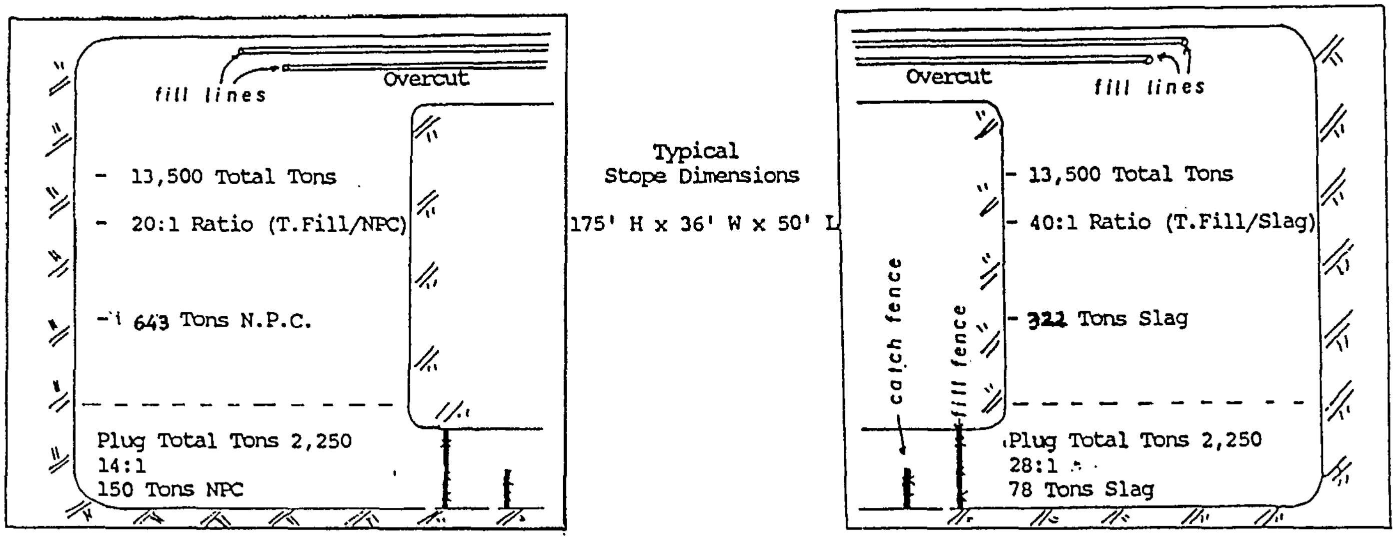
a) Only Portland cement.

b) Only slag "A" with a 1:1 replacement ratio of slag:cement

c) Only slag "A" but with an approximate replacement rate of 0.5:1 slag:cement.

Case (c) is considered to be conservative because data indicates that, as a result of the much higher 28 day strength of slag over cement (up to four times), considerably less slag could be used and still equal the 28 day strength of cement.

ECONOMIC COMPARISON
SLAG CEMENT VS PORTLAND CEMENT



HALF BINDER EXAMPLE

FIGURE 8: STOPE DATA

Binder Ratios, Costs & Savings

BINDER USED	AREA	RATIO FILL:BINDER	STRENGTH AT 28 DAYS (Psi)	TONS BINDER (Tons)	TOTAL TONS (Ton)	BINDER $/TON ($)	TOTAL COST ($)	SAVINGS ($)
a) Cement	Plug	14:1	58	150				
	Stope	20:1	35	643	793	105	83265	
b) Slag "A"	Plug	14:1	170	150				
	Stope	20:1	105	643	793	75	59475	23790
c) Slag "A"	Plug	28:1	83	78				
	Stope	40:1	48	322	400	75	30000	53265

Binder Costs and 28 Day Strengths

STOPE	TONS OF BINDER	PORTLAND CEMENT (a)		SLAG "A" Full Replacement (b)		SLAG "A" Half Replacement (c)	
		Cost ($)	Strength (Psi)	Cost ($)	Strength (Psi)	Cost ($)	Strength (Psi)
Plug Pour	150	15750	58	11250	170	5625	83
Bulk Pour	643	67515	35	48225	105	24113	48
Total	795	83265		59475		29738	

Binder Cost Per Ton of Fill and Savings

Binder	Binder Cost/Ton Fill ($/Ton)	Savings Over Portland Cement ($/Ton Fill)	Savings Over Portland Cement ($/Stope)
a) Portland Cement	5.30	-	
b) Slag "A"	3.79	1.51 (28%)	23850
c) Slag "A"	1.89	3.41 (64%)	53662

Note-Savings are for a fill with 5% binder added

Figure 9: Cost Comparison Using Slag "A" vs. Portland Cement

Conclusion:

Both laboratory and field tests indicate that there are considerable cost savings and quality improvements possible to the hydraulic tailings backfill from Strathcona Mill when slag cement "A", activated with lime, is used as a binder in place of Portland Cement. The binder cost savings can be in excess of 65% and fill strength improvement of up to 350%.

One consideration in using slag cement as a binder is that it takes up to four days for the fill to obtain a strength equivalent to fill consolidated with Portland cement.

At this time there are few mines in the world which are using slag cement in their backfill, so it is suggested that each mine that wishes to consider this improvement develop a site specific plan for testing the replacement of the currently used binder.

P. Hopkins

M. Beaudry

A P P E N D I X

Chemical and Physical Properties of Four Hydraulic Backfill Binder Alternatives

Chemical Composition:

Chemical	Portland Cement (%)	Slag "A" (%)	Slag "B" (%)	Type-C Fly Ash (%)
CaO	65	33	35	17
SiO2	20	38	40	47
Al2O3	4	8	7	19
Fe2O3	3	trace	1	7
MgO	3	16	12	3
SO3	3	1	4	7
S	0	0	0	0
Na2O + K2O	1	1	trace	0
MnO	0	1	0	0
TiO2	0	0	trace	0
SrO	0	0	trace	0
Mn2O3	0	0	1	0
Other	1	2	0	0
Total %	100	100	100	100

Fineness of Grind:

Blain (cm^3/g)	3500	4600	4200	4000-7000

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