Study on the Properties of Cemented Saline Tailings Backfill

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Summary This paper deals with the properties of tailings fill cemented by two different binding agents: Ordinary Portland Cement (OPC) and a special binding agent called High Water and Quick Setting cement (HWQS). Specific emphasis was placed upon the exploration of potential applications of saline tailings prevailing in the Goldfields region of Western Australia for mine backfill purposes. Included in this paper are the testing results of the properties of tailings fill with a range of salinity and cemented by either OPC or HWQS. Recommendations for the selection of binding agent for the design of tailings-based mine backfill are provided.

1 INTRODUCTION

In the Goldfields region of Western Australia, fresh water is in serious shortage, and with this reality, saline ground water is the only choice for most of the mineral processing plants. Consequently, the tailings slurries from mill plants are also highly saline. The typical salinity of the ground water and the water in the tailings slurries in the Goldfields range from 80000 to 200000mg/L TDS (Total Dissolved Solids), of which 90% is Na^+ and Cl^-[1].

In general, the salinity of the water used to prepare cemented products has an adverse impact on their properties, especially their strength characteristics. The higher the salinity of water, the lower the strength of cemented products mixed with this kind of water. In view of the highly saline ground water and tailings prevailing in the Goldfields region of Western Australia, a challenge is to determine the degree of influence of water salinity on the properties of cemented tailings fill. This would allow the economical and technical evaluation of the application of saline tailings for cemented backfill. With these initiatives, an investigation on the properties of cemented tailings fill was initiated in early 1997, with the preliminary laboratory testing results[2] being reported by Wang (1997). This study showed the technical potential for the application of saline tailings for mine backfill.

The backfill investigation started in Jan., 1998 with the saline tailings slurry provided by the Mill Plant of Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM). The binding agents used in this investigation were Ordinary Portland Cement (OPC) and HWQS separately. HWQS used in this investigation was supplied by China University of Mining and Technology. For both types of binders, water with a range of salinities was used to mix the tailings solids. A comparison between the properties of tailings-fill including water having different salinity and different types of binders was then undertaken.

2 TESTING MATERIALS

In total, three types of materials were combined in this study, i.e. tailings, water with different salinity and binding agents (OPC and HWQS).

2.1 Tailings

Fresh unclassified gold tailings slurry from the KCGM mill plant, comprising almost 50% tailings solids and 50% highly saline water was sampled. The Total Dissolved Solids (TDS) determined was 208000mg/L. Separation of saline water and tailings solids was conducted so that the fill samples could be prepared according to a designed solids/water ratio.

The particle size distribution of the tailings provided by KCGM [3] is presented in Table 1.

Table 1. Particle size analysis results

Particle size (micron)	Cumulative percent passing (by weight)
300	97.5
212	91.3
150	82.2
106	73.6
75	65.4
53	60.8
38	55.5
0	0

2.2 Binding agents

One binding agent used was Cockburn Cement for General Purpose.[4] .

The other binding agent used was HWQS cementitious material, which was specifically designed for underground use[5]. This material is composed of two kinds of solid powder material, i.e. substance A and substance B. A and B are usually separately packed before they are put into use (mixed). The method of using HWQS is to mix A with water (or plus aggregates) and mix B with water (or plus aggregate) separately and transport slurry A and B separately. After being transported to the destination where fill placement is to take place, slurry A and B are put together and placed into mined-out voids. As HWQS is capable of reacting with a large amount of water, the water/cement ratio by weight can reach 2.5-3.0 or even higher. The volume of solidified water in pure HWQS-water compound after the completion of hydration can be as high as over 88-90%. The pumping life of slurry A and B before being mixed together is up to 3 days.

The other distinctive properties of HWQS compared to OPC are quick setting and high early strength. After slurry A and B are mixed together (at A/B ratio of 1), the chemical reaction and solidification take place immediately with an initial setting time ranging from 10 to 20 minutes and a final setting time being 30 to 40 minutes. Uniaxial compressive strengths of HWQS with a series of W/C ratio at different stages of curing process are presented in Table 2.

2.3 Water

Two types of water were used to prepare the fill samples, i.e. saline water and fresh water. The salinity of the water used to mix the tailings solids and binding agents varied from 0, 5%, 10% and 20.8% for fill samples of different recipe. (1% water salinity is equivalent to a TDS of 10,000ml/L.)

3 TEST SAMPLE PREPARATION AND CURING

3.1 Sample size and preparation

Samples 50mm in diameter and 100mm high were cast in a mold made of PVC pipe. Both ends of the sample were trimmed and made parallel after the sample had set and hardened. The samples were demolded and cured in a curing tank with the relative humidity and temperature being controlled at 96-98% and 23-27°C respectively.

3.2 Sample batches

Two categories of samples were prepared and tested, i.e. OPC-based tailings fill and HWQS-based tailings fill. For both categories of fill samples, 70% solids by weight was designed as a fill slurry density, which is the typical density for hydraulic fill in practice. Tailings solids/binder ratios of 92:8, 94:6 and 96:4 by mass were adopted for both fresh water samples and saline water samples. The salinity of the water used is as mentioned above. Table 3 lists all the sample compositions of this investigation.

Table 3 Compositions of samples with 70 Wt% density

Type of binder	Tailings/binder proportion, Wt %		Water salinity
	Tailings solids	Binder	(%)
Either HWQS or OPC	92	8	0
	94	6	0
	96	4	0
	92	8	5
	94	6	5
	92	8	10
	94	6	10
	92	8	20.8
	94	6	20.8
	96	4	20.8

4 TESTING EQUIPMENT

The samples were tested under Triaxial Compression. A confining pressure of 0.1MPa was applied, which was achieved by using a pressure-adjustable air compressor and air pressure reservoir. The loading rate of the test machine was set at 1~2 kN/min. The testing system is presented in Figure 1.

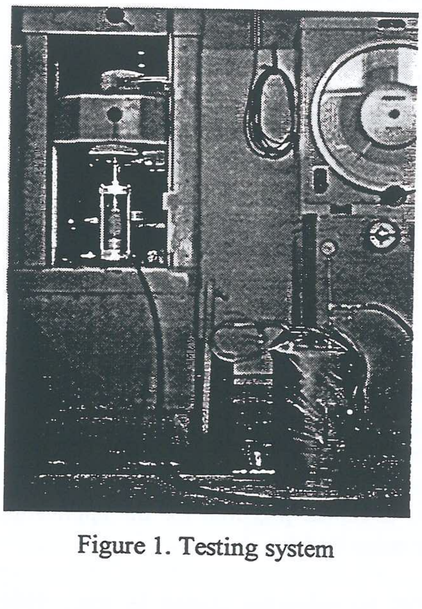

Figure 1. Testing system

Table 2 Mechanical properties of High Water and Quick Setting cement at different W/C ratios

Batch No	W/C Ratio	Water Content (% volume)	HWQS Consumption (kg/m^3)	Initial setting time (minutes)	Uniaxial Compressive Strength (MPa)				
					2h	24h	3d	7d	28d
1	1.00:1	74.36	743	1~1.5	12	18	20	25	30
2	2.00:1	85.20	426	14	3.33	6.26	7.27	7.92	8.70
3	2.25:1	86.60	385	15	2.42	4.74	5.38	6.19	7.08
4	2.50:1	88.00	352	15	1.78	3.93	4.64	4.74	5.32
5	2.75:1	88.80	323	14	1.30	3.08	3.57	3.84	4.22
6	3.00:1	89.70	299	15	0.92	2.54	2.99	3.22	3.60

5 TEST RESULTS

Compressive failure stress of cemented fill samples were determined under a confining pressure of 0.1 MPa and at a curing age of 24 hours, 3 days, 7 days and 28 days.

The values for the early mechanical properties (at a curing time of 24 hours, 3 days and 7 days) were calculated from the mean of two tests. The values for the 28 days mechanical properties were calculated from an average of three tests. Each value reported is the total stress on the specimen at the failure, that is, the applied vertical stress plus the cell pressure [6].

5.1 Properties of Tailings Fill Constituted with Fresh Water

The properties of backfill containing tailings solids and fresh water (using OPC and HWQS as binding agents) are presented in Table 4 and Figure 2.

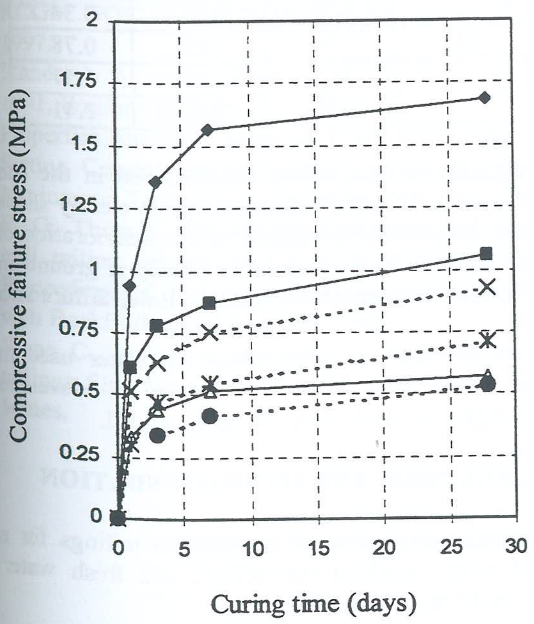

Figure 2. Compressive failure stress of cemented tailings fill containing fresh water at a confining pressure at 100kPa
♦, ■, Δ—HWQS-based fill at Tailings/Binder ratios of 92:8, 94:6 and 96:4 respectively
×, *, •—OPC-based fill at Tailings/Binder ratios of 92:8, 94:6 and 96:4 respectively

It can be seen, from Figure 2, that, for fresh water based samples, the compressive failure stress of HWQS-based fill is almost two times that of OPC-based fill for all curing times. For example, a backfill sample containing 6 Wt% HWQS showed a higher failure stress than a sample containing 8 Wt% OPC for each stage of curing.

Monitoring the physical behavior of fill samples immediately after the fill samples were cast revealed the drainage situation of backfills containing different types of binder. For HWQS based backfill samples, neither percolation nor sample shrinkage were observed. By contrast, both water percolation and shrinkage were observed in the OPC-based samples for all the ranges of OPC content. The conclusion reached is that a potential exists for the application of unclassified tailings in conjunction with HWQS.

5.2 Properties of Backfill Constituted with Saline Water

As was previously described, samples containing water having a salinity of 5%, 10% and 20.8% were prepared and tested separately for both HWQS-based fill and OPC-based tailings fill. The properties gained are presented in Table 5 and 6.

5.2.1 Backfill Containing 5% and 10% Water Salinity

The backfill properties are presented in Table 5, which shows that, for 5% water salinity, HWQS-based tailings fill still has a 28 days failure stress 10% higher than an OPC-based tailings fill for both Tailings/Binder ratios of 92:8 and 94:6. However, for a sample containing 10% water salinity, no difference on failure stress of fill cemented by either binder was determined (28-day curing age).

5.2.2 Backfill containing a 20.8% water salinity

The properties of backfill containing 20.8% water salinity are presented in Table 6.

A comparison between the failure stresses of HWQS-based fill and OPC-based fill indicates that, for tailings fill containing water of 20.8% salinity, OPC-based fill would achieve a higher failure stress than HWQS-based fill.

Table 4 Properties of cemented tailings fill made of fresh water at a density of 70 Wt %

Type Of Binder	Tailings/Binder Proportion		Salinity of Water	Shrinkage	Water Percolation	Compressive Strength (MPa) (A Confining Pressure of 100kPa)			
	Tailings	Binder	(%)			24h	3d	7d	28d
HWQS	92	8	0	NO	NO	0.94	1.36	1.57	1.68
	94	6	0	NO	NO	0.61	0.78	0.87	1.06
	96	4	0	NO	NO	0.33	0.44	0.52	0.57
OPC	92	8	0	Observable	YES	0.52	0.63	0.76	0.93
	94	6	0	Observable	YES	0.30	0.47	0.55	0.71
	96	4	0	Observable	YES		0.34	0.42	0.53

Table 5 Properties of tailings fill containing 5% and 10% water salinity

Type of Binder	Proportion of Tailings to Binder		Salinity of Water	Shrinkage	Water Percolation	Compressive Failure Stress (MPa) (A Confining Pressure of 100kPa.)
	Tailings	Binder	(%)			28 days
HWQS	92	8	5	NO	NO	0.94
	94	6	5	Observable	YES	0.66
	92	8	10	NO	NO	0.82
	94	6	10	Observable	YES	0.57
OPC	92	8	5	Observable	YES	0.84
	94	6	5	Observable	YES	0.60
	92	8	10	Observable	YES	0.81
	94	6	10	Observable	YES	0.58

Table 6 Properties of tailings fill containing 20.8% water salinity

Type of Binder	Proportion of Tailings to Binder		Salinity of Water	Shrinkage	Water Percolation	Compressive failure stress (MPa) (A Confining Pressure of 100kPa.)			
	Tailings	Binder	(%)			24h	3d	7d	28d
HWQS	92	8	20.8	NO	NO	0.45	0.57	0.62	0.76
	94	6	20.8	Observable	YES	0.31	0.38	0.44	0.49
	96	4	20.8	Observable	YES		0.28	0.31	0.34
OPC	92	8	20.8	Observable	YES	0.42	0.54	0.63	0.78
	94	6	20.8	Observable	YES		0.40	0.48	0.57
	96	4	20.8	Observable	YES		0.33	0.37	0.41

6 INFLUENCE OF WATER SALINITY ON THE PROPERTIES OF TAILINGS FILL

The compressive failure stresses of fills containing 8% and 6% binder content in solids with salinity of water are presented in Figure 3.

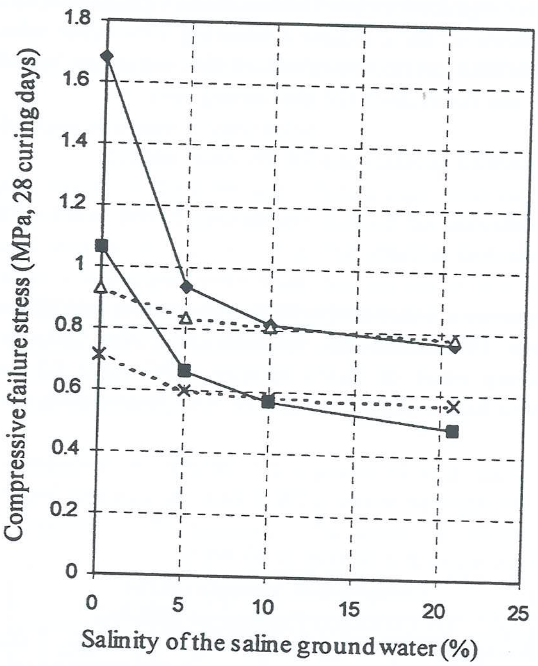

Figure 3 Backfill failure stress with water salinity (A confining pressure of 100kPa was applied.)
◆, ■—HWQS-based fill at Tailings/Binder ratios of 92:8 and 94:6 respectively
Δ, ×—OPC-based fill at Tailings/Binder ratios of 92:8 and 94:6 respectively

The reduction in compressive failure stress in the backfill caused by the salinity of ground water is clearly shown in Figure 3. In general, the degree of the deterioration of fill strength depends on the amount of salinity of ground water. For all cases, a higher salinity means a lower failure stress.

Figure 3 also indicates that when the water used has a salinity higher than 10%, OPC-based fill developed a slightly higher strength than HWQS-based fill.

7 CONCLUSION AND RECOMMENDATION

The potential application of unclassified tailings for mine backfill exists, provided that HWQS and fresh water are used to make the tailings fill.

The salinity of water used to make cemented fill has larger influence on the strength of HWQS-based fill than on OPC-based fill. For cases of low salinity (<10%), HWQS is preferred to OPC for the application of saline tailings fill. Otherwise, the OPC based fill is recommended.

As far as the Goldfields tailings is concerned, with their typical TDS of 80000~200000 mg/L as introduced previously, the option between HWQS and OPC for cemented backfill binding agent should be made on the base of the individual salinity of the ground water which is proposed to be used to prepare the cemented backfill.

The preference of using either OPC or HWQS for a potential cemented backfill application would also be identified by comparing OPC vs. HWQS for the cost implications and handling implications

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