In situ properties of cemented paste backfill in an Alimak Stope

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ABSTRACT

It has been recognized that in situ field data are essential in optimizing the geomechanical design of Cemented Paste Backfill systems. This paper presents the in situ properties of cemented paste backfill specimens obtained from a 149 m high Alimak stope. The in situ specimens include (i) the core samples obtained from the vertical borehole drilled from the overcut three months after the initial pour, (ii) the core samples obtained from three boreholes drilled horizontally from the undercut eight months after the initial pour, and (iii) block samples excavated from the undercut immediately after the fill fence was removed nine months after the initial pour. The physical and structural properties, including water content, void ratio, degree of saturation and unconfined compressive strength (UCS), were determined. The bulk properties of block samples extracted from behind the fence nine months after the initial pour include the void ratio of 1.02 +/-0.05, gravimetric water content of approximately 38.8%, and degree of saturation of approximately 100%. The mean UCS of block sampled CPB from the undercut of the test stope are lower than the 56 day UCS obtained for CPB sampled at the paste plant during the filling of the test stope (309 kPa compared to 359 kPa). This discrepancy is thought due to the better mixing of the laboratory samples as air bubbles and structures were observed in the samples collected from the draw point of the stope, and slight damage of the samples could be expected during extraction from the stope. Two further field studies are in preparation in which pressures induced in longhole stopes will be monitored during backfilling. In situ sampling will be conducted in both of these tests to complement the results here presented.

RÉSUMÉ

Il a été reconnu que les données de in situ sont essentielles dans optimise le design de géomécanique de systèmes de remblai de pâte cimentés. Ce papier présente les propriétés de spécimens de in situ de remblai de pâte cimentés a obtenu d'un 149 m haut de gradin de Alimak. Les spécimens de in situ incluent (i) les échantillons de base obtenus du trou vertical foré de le niveau supérieur trois mois après que les initiaux versent, (ii) les échantillons de base obtenus de trois trous forés horizontalement du le niveau plus bas huit mois après l'initial versent et (iii) les spécimens de bloc ont obtenu de derrière la clôture neuf mois après l'initiale versent. Les propriétés physiques et structurelles, comme le contenu d'eau, l'indice de vide, le degré de saturation et de force de compression (UCS), ont été déterminé. Les propriétés de masse d'échantillons de bloc ont extrait de derrière la clôture neuf mois après l'initial versent incluent l'indice de vide de 1,02 +/-0.05, contenu d'eau gravimétrique d'approximativement 38,8%, et degré de saturation d'approximativement 100%. L'UCS moyen de spécimens de bloc de CPB pris au niveau plus bas est plus bas que l'UCS après 56 jours a obtenu pour CPB de à la plante de pâte pendant la versent du gradin de test de Alimak (309 kPa a comparé à 359 kPa). Ce désaccord est pensé en raison du meilleur mélanger des échantillons de laboratoire comme les bulles d'air et les structures ont été observées dans les échantillons recueillis du dessine le point du gradin de Alimak, et les dommages insignifiants des échantillons pourraient être prévus pendant l'extraction du gradin de Alimak. Deux plus amples études de champ sont dans la préparation dans laquelle fait pression sur induit dans les arrêts de trou long sera contrôlé pendant la versent. In situ' essaie sera dirigé dans les deux de ces tests pour compléter les résultats ici présenté.

1 INTRODUCTION

Cemented Paste Backfill (CPB) has advantages over conventional backfill systems in terms of rapid transport to stopes, and the diversion of tailings from surface storage. There is currently a lack of field data pertaining to backfill induced pressures, the rate of strength gain, and ultimate strength of the backfill. These factors are critical in the design of barricades or fences to contain the fill, and as such, the lack of data mandates a conservative approach to fence design. Furthermore, conservative pouring strategies are often adopted, whereby a paste plug is initially poured and allowed to cure before the main volume of the stope is poured. There is great potential therefore in increasing the efficiency of the backfill system through a better understanding of the in-situ behaviour of CPB.

A large scale field test has been conducted in a 149 m (down dip) length Alimak stope. Instrumentation was deployed to monitor total pressures (using total pressure cells), pore water pressures (using piezometers), and negative pore water pressure (using heat dissipative sensors), and volumetric water content (using Decagon within capacitance probes) the backfill. The instrumentation were assembled in protective cages, and deployed at various depths throughout the stope. The preliminary results of this field test are presented elsewhere (Grabinsky et al., 2007, Grabinsky et al., 2008, Thompson et al., 2008).

To complement the above field study, we have conducted an extensive field sampling program whereby CPB was extracted from the stope by diamond drilling and block sampling. This sampling allows laboratory testing of the actual placed CPB, in terms of bulk property analysis and Unconfined Compressive Strength (UCS) testing. This information may help verify some of the in situ monitored data, such as field volumetric water content and degree of saturation. The need for sampling and testing of in situ specimens arose from the fact that the properties of the CPB samples prepared in the laboratory or cast using CPB produced in a paste plant may differ from the CPB that was allowed to cure in the stope (i.e., in situ) (le Roux et al., 2005). Some of the differences between the lab-cured samples and in situ samples include scale effects and different curing conditions and placement techniques. The in situ sampling here presented will be used as a control to ensure later laboratory studies featuring (laboratory prepared) samples from the same tailings stream have similar properties to, and can be used to model the in situ CPB. A complete understanding of the CPB system can only be achieved by assimilating focused laboratory studies with large scale field tests.

2 MATERIAL AND SITE DESCRIPTION

The cross section of the Alimak test stope is shown in Figure 1. The length of the Alimak test stope was 149 m in length, dipping 69°. The CPB is prepared at the paste plant located at the surface, and is delivered to the stope (overcut level) using pipelines in combination with positive-displacement pumps. After reaching the overcut, the paste entered the stope via a feeder borehole that was drilled from the overcut. In this way, the CPB was directed away from the instrumentation and cables that were deployed down the raise.

The stope was backfilled with CPB consisting 3% binder (1:1 Portland cement:fly ash), 97% mine tailings and water, mixed together at the paste plant. The gravimetric water content of the CPB, defined as the mass of water/mass of dry solids, was approximately 38% to 39% as determined at the paste plant and underground prior the stope backfilling. The slump was measured as 8" at the paste plant. The particle size distribution of the tailings is shown in Figure 2.

During the pouring of the stope, CPB was sampled every three hours both at the paste plant and underground, before the CPB entered the stope. UCS testing was performed on these samples after 1, 2, 7, 28, and 56 days of their collection. The mean UCS values are shown in Figure 3. The mean 56 day strength was found to be 359 kPa and 319 kPa for paste plant and underground samples, respectively. This difference is accounted for by differences in sample storage; the paste plant samples were immediately stored in a humidity controlled room in the paste plant. The underground samples designated for 1, 2 and 7 day testing were immediately transported to the humidity controlled room on surface whereas the remaining samples were stored underground for \sim 10 days prior to transportation to the humidity controlled room.



Figure 1: Schematic presentation of the Alimak test stope.

The test stope was backfilled in five stages, between February 16th and April 6th, 2007, as summarised in Figure 1. Typically stopes are filled in two stages (i.e. plug fill, then main fill) but deviation from this strategy was mandated by a combination of demands for CPB elsewhere in the mine and scientific opportunities to study the effect of production blasting on fresh CPB.



Figure 2: Particle size distribution of the mine tailings.



Figure 3: Mean UCS of samples after 1, 2, 7, 28, and 56 days of curing. Samples of fresh paste were collected at the Paste Plant and underground at the stope overcut

3 FIELD WORK AND SAMPLE PREPARATION

3.1 In Situ Sampling

The in situ paste specimens were obtained by drilling and block sampling at various locations at the Alimak test stope (stope 55, 9555 level overcut) in the period between May and November 2007. The sampling was performed in three stages, and sampling locations are shown in Figure 4. Firstly, drilling from the overcut level parallel to the dip of the stope was performed in May 2007 (i.e., three months after the initial pour) (Figure 4.a). Secondly, horizontal or low angle drilling was conducted from the undercut level in October 2007 (i.e., eight months after the initial pour) (Figure 4.b). Finally, block samples of CPB were removed from the draw-point of the stope when the fill fence was removed, in November 2007 (i.e., nine months after the initial pour). This location is shaded on Figure 4.b and Figure 5 shows a photograph of the CPB face during the remote mucking of the backfill, from which the samples were collected.

Drilling was conducted using a Versa Drill Kmb 0.8 diamond drill. Core from the overcut and undercut drilling was NQ size. It was intended to use triple tube core barrel, as recommended by Grabinsky and Bawden, (2004) but there were problems with the triple tube set up so double tube was used. For conventional double tube drilling, faster drill penetration was found to produce optimal recovery, although it is thought that the drilling process caused a significant reduction in the UCS of the recovered core as will be discussed later. It is intended to repeat the process of diamond drilling in cemented paste backfilled stopes at two further mine sites using triple tube core barrel.

Twelve large samples (~ 70 cm x 50 cm x 50 cm) were obtained from the face of the backfill. This was facilitated by removal of the fill fence, and mucking of CPB a distance of 5 m into the stope (a volume of ~ 5 m x 5 m x 12 m). The samples were obtained from throughout this volume.



Figure 4: Sampling locations at the Alimak test stope: a. stope cross section, b. undercut plan section.

3.2 Sample Handling and Sample Preparation

After extraction, the individual core samples were wrapped in a plastic cling wrap and placed in the core boxes, which were then covered with wet towels and stored in the plastic bags to prevent water evaporation/drying of the paste. The block samples, after being excavated from behind the fill fence, were put in the plastic bags, and placed in the air-tight containers. The samples were then transported to the laboratory at the University of Toronto where they were stored in a high humidity room, with relative humidity of 85% or higher. Prior to testing, the samples were extracted from the packing and trimmed to a desired size depending on the test requirements. In the UCS test, the specimens were cut to achieve a length to diameter ratio of 2:1 (diameter = 50 mm). For void ratio and degree of saturation testing,

the samples, weighing around 10 to 15 g, were trimmed to eliminate sharp edges prior testing.



Figure 5: Block sampling from behind the fill fence with a Total Earth Pressure Cell visible in fill.

4 TEST METHODS/PROCEDURES

Test methods used in this study include determination of in situ bulk properties, such as water content, void ratio, unit weight and degree of saturation, and strength test on in situ cemented paste backfill specimens.

The initial field moisture content was determined using freshly mixed paste at the mine site. Moisture contents for the core samples were tested in the laboratory in Toronto. The moisture content was determined on the block samples obtained from behind the fill fence both in the mine and in the laboratory in Toronto to verify moisture was not lost during transportation.

The void ratio e of the paste, defined as a volume of voids/volume of solids, was determined in the laboratory using the 'wax method'. After applying the soil phase relationships, void ratio was calculated as follows (eq.1)

$$e = \frac{G_s \cdot \gamma_w}{\gamma_d} - 1 \tag{1}$$

where: G_s – specific gravity of solids; γ_w – unit weight of water; γ_d – dry unit weight. Dry unit weight is a ratio between a dry weight of the paste and the total volume. The total volume was determined based on the initial mass of the paste, the mass of the paste specimen covered with the wax film, and the mass of the waxed paste specimen after it has been submerged in the water. At least two samples were measured each time to check the reproducibility.

Degree of saturation S of the paste was calculated based on the void ratio e, specific gravity G_s and water content ω of the paste as follows

$$S = \frac{w \cdot G_s}{e} , \%$$
 [2]

UCS testing was performed using ELE International Digital Tritest 50 load frame, capacity 50 kN, Artech load cell, capacity 2500 lb, and an LVDT displacement transducer in conjunction with the ICP.CON 7016 acquisition moduli and DaisyLab 8.0 system. The loading rate was 0.5 %. Prior to testing, the samples were extracted from the storage boxes and trimmed to a required size. Dimensions of the specimen (e.g., height and diameter), water content and mass of the specimen were measured prior each test. During testing, load (kg) and displacement (mm) were monitored.

5 TEST RESULTS

5.1 Core Samples from a Overcut Borehole

In situ bulk properties of the CPB cored from the overcut borehole are shown in Figures 6 and 7. The average water content of the freshly mixed paste, determined at the paste plant during the Pour Phase 1, ranges between 35.5% and 42% (Figure 6). The water content of the insitu specimens varies between 36% and 43%, which indicates that no significant loss of water took place in the backfilled test stope during the first three months of curing.

UCS for core samples from the overcut were measured, ranging between 35 and 155 kPa. However it is thought that the drilling process damaged the samples as the strength is significantly weaker than that expected. Degree of saturation and void ratio are presented in Figure 7. The data indicates these two bulk parameters remain fairly constant over the entire stope height.



Figure 6: Variation in water content with stope height for 3-month-old paste cored from overcut.



Figure 7: (a) Variation in degree of saturation and (b) void ratio for specimens cored from the overcut.

5.2 Core Samples from Horizontal Boreholes

In situ bulk properties and strength data for core samples acquired 8 months after the pour from three horizontal boreholes are shown in Figures 8 and 9. The strength vary from 90 kPa for soft specimens (Hole 4) to around 300 kPa for specimens from Holes 3 and 5, which appear drier and harder than the soft specimens from Hole 4 (Fig 9). Based on the consistency of samples obtained from the block sampling, it is suggested that the weaker samples were damaged during coring. That the undercut core samples were stronger than those obtained from the overcut drilling is attributed to the lack of head pressure when coring horizontal or inclined boreholes. The degree of saturation and void ratio for samples from this location remain approximately 100% and 1, respectively, (Fig. 9).

5.3 Block Samples from Behind the Fence

In situ bulk properties and strength data for block samples acquired from behind the fill fence 9 months after the pour are shown in Figures 10 and 11. Figure 12 shows the typical internal structure of the sampled CPB. The block samples had dark gray colour and appeared wet and not weathered, unlike the specimens obtained from horizontal boreholes no. 3 and 5 in the close proximity to the fill fence a month earlier, which we assume was due to oxidation during transportation. No signs of oxidation or desiccation were observed on the block samples. There were however air bubbles and planar structures which could be expected to reduce the samples' UCS. The average UCS of the CPB from behind the fill fence was 310 kPa, gravimetric moisture content was 38.8%, the degree of saturation and void ratio were 100% and 1. respectively. The test results indicate that there is no significant change in water content, degree of saturation and void ratio of the paste after 9 months of curing in the Alimak test stope as compared to the freshly mixed paste,

for which water content, void ratio and degree of saturation are approximately 38-39%, 1, and 100%, respectively (Moghaddam, 2008).



Figure 8: UCS of 8-month-old paste cored from undercut.



Figure 9: a. Degree of saturation, b. Void ratio of 8-monthold paste cored from undercut.

The changes in the water content of the in situ paste obtained using non-destructive field monitoring in the stope and in the lab are shown in Figure 13. The field monitoring data agrees well with the laboratory test results acquired on in situ specimens, which show that the water content of the paste in the backfilled stope remains mostly unchanged during the period of 9 months of curing. The visible fluctuations in the instrument readout correspond to the perturbations in the EM properties of the paste caused by the changes during the early stages of hydration process (B), and material perturbations caused by additional pouring of the paste (C), production blasting and sample drilling/coring through the stope in the close proximity to the instrumentation (D).



Figure 10: UCS and moisture content of 9-month-old paste sampled from behind the fill fence.



Figure 11: a. Degree of saturation, and b. Void ratio of 9month-old block samples from behind the fill fence.

6 DISCUSSION AND CONCLUSIONS

This paper presents the bulk properties and UCS of CPB obtained from a backfilled Alimak stope at various locations in the stope. This study showed that within the resolution of this study, there is no significant change in water content, void ratio and degree of saturation of the CPB. The UCS samples taken from behind the fill fence provided UCS measurements (~ 310 kPa) that were slightly weaker than the UCS values obtained for laboratory prepared specimens sourced from the paste plant during the pouring of the same stope. These differences are attributed to the presence of heterogeneity in the in-situ samples, for instance air bubbles and planes of weakness were observed, whereas laboratory samples

undergo mixing during casting. Furthermore, some damage to samples could be expected as the CPB was extracted from the stope. The diamond drill coring in the undercut also provided UCS strengths in the range of the laboratory prepared samples. As a postscript to this field study, the stope adjacent to the instrumented stope was subsequently mined and no significant CPB dilution was observed, indicating the suitability of the backfill's strength properties.

Two further field tests are currently in preparation in which backfilling of longhole stopes will be monitored using similar instrumentation to that described earlier in this paper. CPB will be sampled directly from the stopes in these future studies, to compliment the work here presented. Work to improve our sampling technique is ongoing; we intend to conduct diamond drilling using triple tube core barrel at very low penetration rates in future studies, in addition to sampling from CPB faces at draw points to get a more complete picture of the UCS and bulk properties of emplaced CPB.



Figure 12: Photograph of CPB sampled from behind the fill fence.



Figure 13: Variations in water content with time in the backfilled test stope. A. the onset of the measurement

(probe gets in contact with paste), B. the onset of the cement hydration (variation in electrical conductivity caused by cement hydration affects the probe's readout), C. fluctuations in the probe's readout caused by further addition of the paste into the stope (pour stages), and D. fluctuations in the probe's readout caused by sampling drilling/coring through the stope.

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