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Effect of polycarboxylated acrylic acid polymer-based superplasticizer on cemented paste backfill

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ABSTRACT

Polycarboxylated Acrylic Acid Polymer-based superplasticizer is a well known in the cement/concrete industry for improving the pumpability and strength characteristics of the paste. This paper explores the effect of this superplasticizer (Admixture PCA) on the yield stress of the freshly mixed cemented paste backfill (CPB) and the strength development in the hardened CPB and its potential applicability in cemented paste backfilling. The rheological, setting and hardening properties of CPB containing Admixture PCA have been investigated using rheological, zeta potential, penetrative resistance, and UCS measurements. The tests indicate that the yield stress of the freshly mixed CPB is reduced from > 1000 Pa in non-treated paste to less than 10 Pa in pastes containing 0.185% by wt of solids of Admixture PCA. Furthermore, the initial time of setting is decreased from original ~9 hours in non-treated CPB to ~7 h in 0.185% by wt of solids of Admixture PCA, while the 28-day UCS strength is increased from original ~450 kPa in non-treated CPB to ~1000 kPa in pastes containing 0.185% by wt of solids of Admixture PCA. The zeta potential measurements reveal that Admixture PCA does not cause changes in the particle zeta potential, thereby implying that the reduction in yield stress is due to steric hindrance.

RÉSUMÉ

Le superplastifiant acide acrylique polycarboxylé à base de polymères (l'additif PCA) est un bien connu dans l'industrie du ciment/béton pour améliorer la fluidité et les caractéristiques mécaniques de la pâte. Cet article traite de l'effet de ce superplastifiant (l'additif PCA) sur la limite d'élasticité apparente (l'évolution temporelle de la fluidité) du remblai cimenté en pâte (RCP) au jeune âge ainsi que du développement de résistance mécanique dans le RCP durci et son applicabilité potentielle dans le RCP. Les propriétés rhéologiques et de durcissement des RCP contenant un superplastifiant ont été explorées en utilisant une variété de techniques. Les épreuves indiquent que la résistance rhéométrique apparente (la limite d'élasticité apparente τ) de RCP est réduite de >1000 Pa dans le RCP sans superplastifiant à moins de ~10 Pa dans les RCP contenant 0.185 % par masse de solides de superplastifiant. En outre, le temps initial de mise est diminué de ~9 heures à l'origine dans le RCP sans superplastifiant à ~7 h à 0.185 % par masse de solides de superplastifiant, alors que la résistance mécanique de 28 jours est augmentée de ~450 kPa à l'origine dans le RCP sans superplastifiant à ~1000 kPa dans les RCP contenant 0.185 % par masse de solides de superplastifiant. Les mesures des potentiels zêta révèlent que ce superplastifiant ne provoque pas de changements dans le potentiel zêta des particules solides, cela impliquant ainsi que la réduction de la résistance rhéométrique (la limite d'élasticité) est due à la répulsion stérique.

1 INTRODUCTION

Cemented paste backfilling is gaining popularity in recent years as an effective method for backfilling underground mine stopes. The CPB-backfilled stopes provide ground stabilization and permit mining of the adjacent stopes in a short period of time when compared to other backfilling techniques, while reducing the amount of tailings for surface disposal. CPB consists of mine tailings, binder (typically cement or mixture of cement and fly ash or blast furnace slag) and water. The solids content typically vary between 68 and 80 wt%. To ensure good flowability and water retention characteristics of the paste, at least 15 wt% of solid particles should be smaller than 20 microns (Landriault 1995). Cement is added to the tailings to increase strength of the hardening paste. Typical cement content in CPB ranges between 2% and 8% by weight of solids, and is controlled by the cost of cement and strength requirements for the backfilled stopes.

The mechanical strength of cemented pastes can be improved by reducing the moisture content of the paste, while maintaining the fluidity of the paste by adding a superplasticizer; this is well documented in cement and

concrete industry (Agarwal et al., 2000; Singh et al., 1992). Thus, the fluidity of the paste backfill is an important parameter in paste design, and so the rheological behaviour of the paste must be well understood in order to optimize its flow characteristics. The main benefits of optimizing CPB are (i) reduced transportation costs (e.g., more efficient pumping), and (ii) reduced risk of plugging pipes. This study focuses on exploring the effect of a superplasticizer, the polycarboxylated acrylic acid-based polymer admixture (Admixture PCA), on the rheological and mechanical properties of CPB. The apparent yield stress and unconfined compressive strength measurements are performed to assess rheological and mechanical behaviour of CPB containing Admixture PCA. To further explore the interaction between the CPB and Admixture PCA, zeta potential measurements were utilized to study particle-particle and particle-fluid interactions.

2 PORTLAND CEMENT HYDRATION

Portland cement (PC) is a reactive phase of cemented paste backfill that undergoes hydration reactions when

brought in contact with water. The hydration process in cement-water pastes has four stages: (i) early reactions (~30 minutes), (ii) induction or dormant period (1 to 3 hours), (iii) acceleration period (3 to 17 hours), and (iv) slow reactions period that occurs after the acceleration period and lasts as long as both unhydrated cement grains and water are available. The *early reactions* include the initial dissolution of PC grains, where fast-dissolving ions, such as Ca^{2+} , Al^{3+} , OH^- , sulphate ions (SO_4^{2-}) and alkali ions (Na^+ and K^+), are released into the pore fluid. During the *induction period*, the semi-permeable protective membrane starts to form around hydrating cement grains, which hinders further hydration. When the membrane around cement grain bursts, the new hydration products, such as calcium silica hydrates (C-S-H), calcium hydroxide or portlandite (CH), and ettringite (AFt), start to form at an accelerated rate. This development marks a new stage of cement hydration termed the *acceleration period*, and during this period the amounts of C-S-H and other hydration products rapidly increase. The last stage of cement hydration is termed the *slow reactions period*, during which the hydration products such as C-S-H and CH continue to form at a reduced speed (Soroka, 1980).

By adding the certain additives, such as CaCl_2 , sodium naphthalene sulfonic acid-based polymer or polycarboxylated acrylic-acid based polymer, one can affect the kinetics of the hydration process in cement-based pastes as these additives act either as accelerators or retarders during the cement-water reactions by enhancing or poisoning the growth of the newly forming hydration products.

3 INTERPARTICLE FORCES AND METHODS OF ASSESSMENT

The behaviour of mineral-water mixtures, including CPB, is affected by physical and chemical properties of the solids (e.g., solids content, particle size, particle shape and mineralogical composition), properties of the solution (pH and ionic concentration of pore solution) and type and magnitude of interparticle forces.

3.1 Interparticle forces

Attraction/repulsion forces that may arise between mineral grains suspended in an aqueous solution include (Tadros 1987):

- (i) Hydrodynamic Forces
- (ii) Brownian Motion (Diffusion)
- (iii) Interparticle Colloidal Forces

The *hydrodynamic force* is the net resultant force of the gravitational force, buoyancy force, drag force, and the force of inertia (Schulze 1984). This force is independent of pH and affects mostly large particles (e.g., particles > 10 microns). *Brownian motion* is the movement of the particles due to the presence of a thermal gradient. Brownian motion only affects very small particles (e.g., particles < 0.1 microns; Laskowski and Pugh 1992). The

third and largest group, *interparticle colloidal forces*, affect only particles smaller than 10-20 microns, and, depending on the nature of the particles and the pore solution, comprise forces such as: van der Waals forces, Born repulsion forces, electrostatic forces, hydrophobic forces, steric forces, hydration forces or structural forces (Johnson et al. 2000; Laskowski and Pugh 1992). The resulting net force controls the type of association the particles tend to form, ranging from dispersed-deflocculated or edge-to-face flocculated, to edge-to-edge flocculated or face-to-face aggregated association, thereby controlling the overall stability of the mineral suspension (van Olphen 1977).

In systems with low electrolyte concentrations and /or large separation distances between particles, the DLVO theory can be applied, which assumes that the net resultant force is the sum of two forces only: the attractive van der Waals force and repulsive electrostatic force (Pashley 1992; Colic et al. 1998). This principle is not applicable to high density mixtures, such as CPB or admixture-enriched cemented pastes, since additional colloidal forces, such as hydration forces, steric forces or hydrophobic forces, may enhance interparticle interactions. These forces are referred to as non-DLVO forces, and may have a significant role in rheological and mechanical behaviour of solid-polymer-liquid suspensions. Thus, in cement-containing mixtures, hydration reactions give rise to hydration forces between the particles, creating a network structure between the particles which gains strength with time as additional particle-particle bonds form and the existing ones strengthen. Contrary to the hydration forces that cause attraction between the particles, the repulsive steric forces may develop between the particles upon addition of a certain chemical admixture (e.g., a retarder or a superplasticizer). The steric repulsion is a result of the adsorption of the admixture onto the particle surface, which acts as physical barrier that inhibits particle-particle interactions and enhances particle-particle repulsion (i.e., steric hindrance) leading to increased fluidity and retardation of hydration process in these pastes.

3.2 Apparent yield stress

Yield stress, defined as the stress required to initiate the flow, is a good indicator of the magnitude of the particle-particle forces. Due to the difficulties and limitations associated with measuring the true yield stress, the yield stress is commonly referred to as apparent yield stress. The apparent yield stress can be measured using indirect or direct methods. The indirect method includes extrapolation of the shear stress to zero shear rate on a shear stress-shear rate profile – a technique that, due to difficulties to precisely determine the shear rate during the vane test, has limitations in high-density mixtures such as CPB. The direct methods include measurement techniques such as *creep/recovery*, *stress relaxation*, and *stress growth* (Liddell and Boger 1996). Because of its simplicity, the stress growth technique, which entails shearing of a material at a low and constant shear rate, where yield stress is determined as the maximum shear stress in the stress-time profile, is gaining popularity in

recent years (Nguyen et al., 2006, Roussel and Coussot, 2005, Liddel and Boger, 1996).

The past work on the rheology of CPB is limited. Ouattara et al. (2010) studied the rheological properties of thickened tailings and cemented paste backfill, while Huynh et al. (2006) measured the yield stress in dewatered tailings and cemented paste backfill using Haake CV20 Rotovisco rheometer with concentric cylinders. Moghaddam and Hassani (2007) studied cemented and non-cemented paste backfill using R/S-CPS Brookfield Rheometer with the six-blade vane. Ercikdi et al. (2010) studied the strength evolution in CPB mixed with water-reducing admixtures to maintain the 7" slump of freshly mixed pastes. Crowder and Grabinsky (2002) studied non-cemented, thickened tailings using a rotational, strain-controlled Brookfield DV-I viscometer with four-blade vane. This study focuses on measuring the apparent yield stress of CPB mixed with a polycarboxylated acrylic-acid based superplasticizer using a modified Brookfield Rotational Viscometer with a vane.

3.3 Zeta potential

The most common colloidal interparticle force in soil-water mixtures is electrostatic force due to the fact that most solid particles carry a surface charge, resulting from isomorphic substitution, broken bonds or ionic arrangement in the crystal lattice. This surface charge is usually balanced by counterions, which in the aqueous environment move away from the surface and form a cloud around the particle called the double layer. The double layer consists of a layer of tightly bound counterions adjacent to the particle surface (i.e., Stern layer) and a diffuse layer, where the concentration of the counterions gradually decreases with increasing distance from the particle surface, eventually reaching the bulk fluid concentration (Lyklema, 1995). It is difficult to directly assess the particle surface potential due to the presence of the tightly bound ions in the Stern layer. However, the potential at the slip/shear plane, known as the zeta potential, can be readily assessed by measuring the electrophoretic mobility of a particle (useful for submicron size particles) or by using electroacoustic spectroscopy (Dukhin et al. 1999a and 1999b). The sign and the magnitude of the zeta potential provide information about the microscale particle-particle and particle-fluid interactions, which govern the macroscale behaviour (e.g., flow behaviour) of particle-fluid mixtures.

4 EXPERIMENTAL PROCEDURE

Experimental procedures for apparent yield stress, zeta potential and unconfined compressive strength tests are described next.

4.1 Apparent yield stress measurement

4.1.1 Specimen preparation

The specimens for the apparent yield stress measurements consisted of mine tailings, deionized water, Portland cement, and a polycarboxylated acrylic

acid-based polymer (Admixture PCA). All specimens contained 5% by wt of solids Portland cement. The characteristics of the mine tailings, Portland cement and Admixture PCA are presented in Tables 1, 2 and 3, respectively. Dry mine tailings were mixed with deionized water for one minute using an electric hand mixer, followed by the addition of other components that were added to the mixture with a one-minute delay for each

Table 1. Characteristics of mine tailings

Parameter	
d_{50} (microns)	18
Specific surface (m^2/g)	0.344
Specific gravity	2.93
Chemical composition (XRF)	
Compound	Content (%)
SiO_2	59.3
Al_2O_3	13.5
S	5.9
Ba	5.2
Fe	4.3
K	3.6
Ca	2
Mg	1.75
Na	1.5
others	3

Table 2. Characteristics of Portland cement

Parameter	
Specific surface (m^2/g)	0.365
Density (g/cm^3)	3.15
Mineralogical composition:	Content (%)
tricalcium silicate (C_3S)	63
dicalcium silicate (C_2S)	11
tricalcium aluminate (C_3A)	9
tetracalcium aluminoferrite (C_4AF)	7
Chemical composition:	Content (%)
SiO_2	18.06
Al_2O_3	3.51
SO_3	4.54
Na_2O	0.086
MgO	3.156
K_2O	0.53
CaO	61.58
Fe_2O_3	2.558

successive component. The time when the Portland cement was added to the mixture was taken to be the start time of the test. In this study, the control specimen, consisting of mine tailings, Portland cement and water, had 28% water content (by total mass), while the specimens containing Admixture PCA had 23% water content. The water content for the CPB specimens containing Admixture PCA was adjusted based on the mini cone slump test (Kantro 1980) data, so that the paste specimen containing Admixture PCA exhibited the same slump as the control specimen.

Table 3. Schematic of Admixture PCA

Superplasticizer	Chemical formula
Polycarboxylated acrylic acid polymer (Admixture PCA)	$\begin{array}{ccccccc} & R & & R & & R & \\ & & & & & & \\ (-CH_2 - C - CH_2 - C - CH_2 - C -) & & & & & & \\ & & & & & & \\ & COOR & & COONa & & X & \end{array} \quad n$

Legend:

C – carbon, H – hydrogen, O – oxygen, Na – sodium, S – sulphur, R – radical agent, X – agent, n – number of polymer molecules in a polymer chain

4.1.2 Apparent yield stress measurement technique

The stress growth technique in conjunction with rotational, strain-controlled Brookfield DV-I viscometer with 4-blade vane were used to study the apparent yield stress in CPB. The specimen is placed in the glass cylinder, and, at selected times, the vane is lowered into the specimen, and torque is applied to commence the rotation of the vane. The resistance (viscous drag) that the specimen exerts during rotation of the vane is measured by a torque cell and expressed as percentage torque T (%).

The shear stress τ [Pa] was calculated using the equations (1) and (2), which take into account the vane geometry (Nguyen and Boger, 1983)

$$\tau = \frac{T}{K} \quad (1)$$

$$K = \frac{\pi D^3}{2} \left(\frac{L}{D} + \frac{1}{3} \right) \quad (2)$$

where T is the measured percent torque (based on the maximum torque of $5.75 \cdot 10^{-3}$ Nm), D is the diameter of the vane (m), and L is the length of the vane (m). The shear stress induced in the specimen due to the rotation of the vane is calculated based on the assumption that the material is sheared along a cylindrical shear plane, defined by the circumscribing circle formed by the tips of the blades, and that the material between the vane blades moves simultaneously with the blades as a solid (Nguyen and Boger, 1983). All tests were repeated twice to ensure the reproducibility of the measurement.

Problems associated with exceeding the torque cell may arise when testing the specimens that have high solids contents, caused by the large number of direct particle-particle contacts, and/or when testing cement-containing specimens, caused by the increased number and strength of particle-particle contacts that result from the continuing hydration of cement grains.

4.2 Zeta potential measurement

4.2.1 Specimen preparation

The specimens for the zeta potential measurements consisted of mine tailings, deionized water and a polycarboxylated acrylic acid-based polymer (Admixture

PCA). All specimens had water contents of 80% (by total mass). Dry solid ingredients were mixed with deionized water for two minutes using a glass stirrer. The suspension was then poured into the specimen holder and circulated for five minutes using a positive displacement pump prior the measurement. In the specimens containing Admixture PCA the required amount of the admixture was dispensed automatically into the mixture, and the mixture was circulated for 5 minutes using the positive displacement pump prior to measurement. Each test was performed twice to ensure the reproducibility of the measurement.

4.2.1 Zeta potential measurement technique

Zeta potential measurements were performed using a DT-1200 Electroacoustic Spectrometer (Dispersion Technology, Inc., New York), which enables the measurement of the zeta potential in high density pastes, such as CPB, based on the specimen's original consistency, pore chemistry, particle size and mineralogical composition. The advantage of this methodology is that it takes into account the overall paste's parameters, whereas in alternative zeta potential measurement techniques the individual solid particles ought to be singled out from the paste sample prior to measurement (Pashley, 1992, Dukhin et al. 1999a, 1999b, and 2001). The pH of the mixture was adjusted by 1 M HCl or 1 M KOH solutions. Chemical reagents, such as pH modifiers or superplasticizers, were dispensed into the specimen using automated, digitally controlled burettes.

4.3 Unconfined compressive strength measurement

The specimens for the unconfined compressive strength measurements consisted of mine tailings, deionized water, Portland cement and a polycarboxylated acrylic acid-based polymer (Admixture PCA). The specimens were prepared using the same procedure as described in the apparent yield stress measurement section: dry mine tailings were mixed with deionized water for one minute, and then the other components (e.g., Portland cement and, where applicable, Admixture PCA) were added to the mixture with a one-minute delay for each successive component. Due to the large quantity of paste needed for the UCS tests, the specimens were mixed using an industrial hand-held drill fitted with a mixing paddle. After mixing, the paste was poured into the cylindrical moulds (~5.2 cm diameter and ~12 cm height). Each mould was sealed with a paraffin film to prevent water evaporation and minimize oxidation, and stored in a high relative humidity room for a desired period of time (e.g., 28 days, 182 days and 365 days) prior to testing. At the time of testing, the specimens were taken out of the high relative humidity room, extracted from the cylindrical moulds and trimmed to obtain a length-to-diameter ratio H/D of 2 (D = 50.0 ± 2 mm, H = 100.0 ± 2 mm). The unconfined compressive strength test was conducted using a loading frame in combination with a data acquisition system. A loading rate of 1% of the sample length per minute (i.e., 1 mm/min) was used (ASTM 2000).

5 RESULTS

5.1 Apparent yield stress

Figure 1 presents a shear stress response for CPB control specimen (28% water content 95:5 MT:PC CPB), hydrated for 15 and 60 minutes. The apparent yield stress, defined as a peak (maximum) value of the shear stress (Nguyen and Boger, 1983), is 180 ± 10 Pa and 600 ± 20 Pa for 15-minute- and 60-minute-old CPB specimens, respectively.

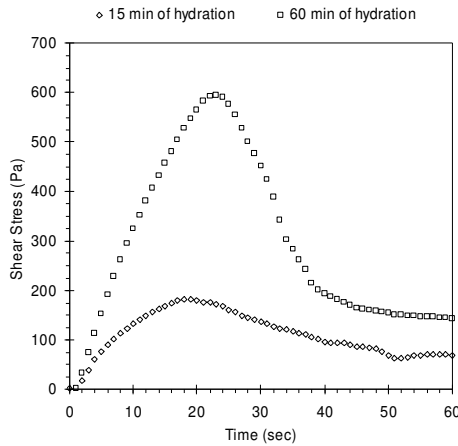


Figure 1. Shear stress-time profile of CPB control specimen (28% water content, 95:5 MT:PC), hydrated for 15 minutes and 60 minutes

The effect of Admixture PCA on the apparent yield stress of CPB is studied next. Figure 2 shows the variations in the apparent yield stress of CPB mixed with selected concentrations of Admixture PCA. The specimens cured for 15 minutes and 60 minutes exhibit a reduction of almost 100% in the apparent yield stress upon addition of 0.3% of Admixture PCA when compared to CPB with reduced water content. The trends are somewhat different when compared to the control specimen. The data suggest that Admixture PCA causes the reduction in the apparent yield stress at all tested concentrations in the 15-minute-old CPB specimens, however, the dosage of 0.185% by wt of solids was not enough to significantly reduce the apparent yield stress in a 60-minute-old CPB specimen. This implies that in case of prolonged CPB transport (e.g., greater distances between the paste plant and the underground stope) or an unexpected interruption in the transport process, a higher than 0.185% by wt of solids dose of Admixture PCA might be required to reduce the apparent yield stress of CPB used in this study. Moreover, the addition of Admixture PCA at concentrations greater than 0.3% causes little variation in the apparent yield stress in CPB cured for 15 minutes and 60 minutes, indicating that this threshold value of 0.3% might be the optimal dosage required for this type of material.

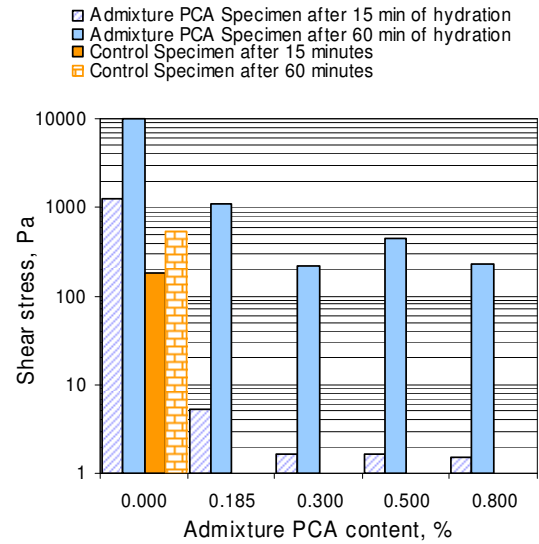


Figure 2. Effect of Admixture PCA on the apparent shear stress of CPB cured for 15 min and 60 min

Fluidity and workability of pastes can also be quantified using the penetrative resistance test, including Vicat needle penetrative resistance test (ASTM C-191, 1998). Specimens containing Admixture PCA have a shorter set time (~7 hours vs. ~9 hours) when compared to the control specimen (28% water content 95:5 MT:PC CPB); however, when compared to the CPB sample with reduced water content (i.e., 25% water content), the Admixture PCA specimen exhibits longer set time (~7 hours vs. 6 hours)(Klein and Simon, 2006).

5.2 Zeta potential

The electroacoustic measurement data show that the mean value of the zeta potential for mine tailings suspended in deionized water is approximately -13 ± 5 mV. The pH of mine tailings-water mixtures in all tests was fairly constant (approximately 6.9 ± 0.2). Relatively large standard deviation for the zeta potential data is most likely due to the inherent heterogeneous mineral composition of the tailings, the variety of crystal faces and physical and chemical imperfections that exist on the surface of the mineral grains, as suggested by Elimelech et al. (2000).

Figure 3 illustrates the effect of Admixture PCA on the zeta potential of mine tailings. Data suggest that the Admixture PCA causes little change to the zeta potential of the mine tailings. This agrees with the fact that the polycarboxylated polyacrylate (i.e., Admixture PCA) is a non-ionic surfactant, whose dispersion action is based on steric forces, not electrostatic repulsion forces. The pH remains unchanged (approximately 6.9 ± 0.2) upon the addition of Admixture PCA.

5.3 Unconfined Compressive Strength (UCS)

The results of the UCS tests are summarized in Figure 4. The reported UCS values represent the arithmetic mean of the maximum stress values obtained from the four stress-strain profiles acquired during testing of four samples, prepared and cured simultaneously. The UCS increases in all specimens over the course of one year of curing. Although there are reported cases where UCS of CPB containing sulphides deteriorates with time (Mitchell and Wong, 1982; Kesimal et al., 2005; Fall et al., 2007), the CPB specimens tested in this study show no signs of strength degradation with time. Furthermore, the CPB specimens containing Admixture PCA exhibit a significantly higher early strength (i.e., 28-day) as compared to the control specimen cured under the identical conditions. The UCS of Admixture PCA-containing specimens continues to increase with time, reaching ~1.7 MPa after 1 year of curing.

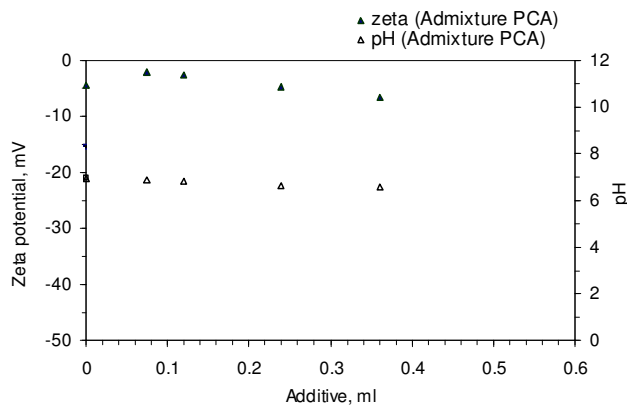


Figure 3. Effect of Admixture PCA on zeta potential and pH of mine tailings-water mixtures

6 DISCUSSION

The action mechanism of the Admixture PCA is based on the admixture's carboxylic group, which is strongly hydrophilic, and, as such, enables dissolution of polymers in water and their adsorption onto the surface of the cement particles. Once adsorbed on the surface of the particles, the admixture's polymers will cause dispersion of cement grains – the phenomenon called steric hindrance (Hanehara and Yamada 1999; Yamada et al. 2000; Prince et al. 2002). Mollah et al. (1995) and Lota et al. (2000) went further in explaining the action mechanism of the admixture's polymers by suggesting that, due to reactions between the anionic carboxylic acid group and Ca^{2+} ions that were previously released from the hydrating cement grains, the number of Ca^{2+} ions available for the formation of the new hydration products (e.g., C-S-H and CH) is reduced, thereby causing a delay in the hydration process and an increase in the fluidity of the fresh cement pastes. The laboratory results from this study suggest that

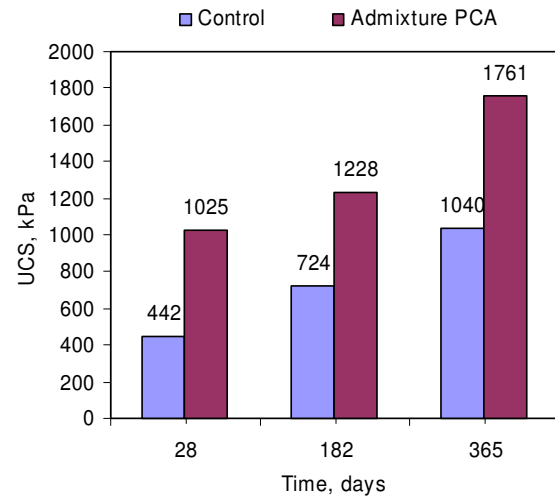


Figure 4. Effect of Admixture PCA on unconfined compressive strength of CPB cured for 28, 182 and 365 days

rheological properties of CPB, such as apparent yield stress, are altered by the addition of Admixture PCA. The apparent yield stress measurement data of CPB containing Admixture PCA suggest that steric hindrance is a very effective dispersing mechanism as it reduces the apparent yield stress by almost 100%. The degree of dispersion of cement grains is sensitive to cement mineralogy as admixture's polymers adsorb differently on different mineral. Furthermore, the fluidity of the paste seems to deteriorate over time. The loss of fluidity over time in the Admixture PCA specimen may be due to the shrinkage of the polycarboxylic chains in the presence of ions in the pore fluid, resulting in a reduced repulsive force between the particles, as proposed by Hanehara and Yamada (1999). Another possible explanation for fluidity deterioration over time may be that the long polymer chains can stretch and/or intertwine (Graham et al. 2003), and cause "bridging" between the adjacent solid particles, causing flocculation (Otsubo and Horigome, 2003) and increase in apparent yield stress in these pastes.

7 CONCLUSION

The rheological, setting and hardening properties of CPB containing Admixture PCA have been investigated using a variety of measurement techniques. Polycarboxylated Acrylic Acid Polymer-based superplasticizer (Admixture PCA) demonstrated a strong potential to improve the fluidity and compressive strength of CPB. The test results indicate that the yield stress of the freshly mixed CPB is reduced from > 1000 Pa for CPB specimens without admixture to <10 Pa in CPB specimens containing 0.185% by wt of solids of Admixture PCA. Furthermore, although the setting time decreased in admixture-containing CPB specimens when compared to CPB without the Admixture PCA, the setting time has increased when compared to CPB specimens prepared at a reduced

water content (i.e., water content equivalent to the admixture-containing CPB). The unconfined compressive strength after 28 days of curing increased from the initial ~450 kPa for CPB without Admixture PCA to ~1000 kPa for CPB containing 0.185% by wt of solids of Admixture PCA. The zeta potential measurement data indicate that Admixture PCA does not affect the magnitude nor the sign of the zeta potential of the mine tailings particles, thereby implying that the reduction in yield stress is not caused by electrostatic repulsion but steric hindrance.

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