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Coupled effects of cement type and water quality on the properties of cemented paste backfill

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ABSTRACT

The significant coagulation delay and poor strength performance of cemented paste backfill (CPB) are two of the biggest challenges faced by the backfilling system in Chihong mine. These factors significantly affect the mining and backfill cycle. Hence, CPB property tests (e.g., slump, coagulation, and strength) were conducted to investigate the influence of different cement types and mixing water qualities (tailings pore water and distilled water). Results of the tests for slump, initial coagulation time (ICT), and unconfined compressive strength (UCS) of the CPB samples are as follows: (i) slump variation of different CPB samples is insignificant. (ii) The ICT changing trends of the CPB samples are in line with the ICT of their mixing cement slurry. In addition, zinc ions in the tailings pore water are detrimental to CPB coagulation. (iii) Cement has an obvious influence on the UCS of CPB, and water quality barely affects the UCS of CPB. These results indicate that cement choice and water chemical components are important factors in CPB design and mine operations.

1. Introduction

During the last few decades, cemented paste backfill (CPB) has become increasingly popular in underground mining operations worldwide (Brackebusch, 1994; Landriault, 1995; Hassani and Archibal, 1998; Fall et al., 2010; Alireza and Fall, 2013). CPB is a mixture of thickened and filtered tailings from the processing operation of mines, water, and hydraulic cement. It contains 70% to 85% solids (tailings and cement) by weight. Cement creates cohesion in CPB through cement hydration, and accounts for up to 75% of the cost of CPBs. Ordinary Portland cement is a traditional cement with a proportion that is commonly 2% to 7% by total weight. A proportion of up to 10% is periodically used to increase the early strength of CPBs (Williams et al., 2001; Kesimal et al., 2003, 2005; Benzaazoua et al., 2004; Klein and Simon, 2006; Orejarena and Fall, 2008). Previous field practice has showed that CPB is capable of swiftly supporting surrounding rocks. Moreover, this technology can reduce the volume of surface tailings disposal, thus minimizing associated geo-environmental problems (Archibald et al., 2000; Yilmaz et al., 2004; Sivakugan et al., 2005; Huang et al., 2011).

Despite the tremendous progress that has been achieved in understanding CPB properties and its affecting factors, major technological challenges remain. One challenge is understanding the coupled effects of cement type and water quality on CPB performance. Only a few studies have examined the effect of binder type (cement and slag) on the mechanical properties and microstructure of CPB (Ercikdi et al., 2009; Fall et al. 2010; Yin et al., 2012). The effect of cement type, which refers to the same cement mark but produced by different companies, on CPB properties has been ignored. Many cement producers can be chosen to provide cement for one mine. The sources of water for CPB preparation may include mineral processing water, underground water, and lake/river water. The chemical components of various sources of water differ. Such difference may affect the reaction of cement to hydration, and therefore, influence the coagulation and strength properties of CPB. However, no study has yet been performed on the coupled effects of cement type (same mark but from different companies) and water quality on CPB properties.

Thus, substantially increasing knowledge on the effects of cement type and water quality on CPB properties is urgent. The main objectives of this research are to experimentally study the following: the effect of cement type and water quality on paste slump performance, coagulation performance, and UCS performance.

2. Experimental program

2.1. Materials

2.1.1. Tailings and granulated slags

The tailings sample (called LZT) used to prepare CPB is total tailings obtained from the Chihong lead/zinc mine. Granulated slag was added into the CPB as a coarse aggregate to increase solid weight percentage,

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Table 1
Physical properties of the tailings and the granulated slag.

Item	Solid density ($t \cdot m^{-3}$)	Bulk density ($t \cdot m^{-3}$)	Porosity (%)
Tailings	2.71	1.88	34.35
Granulated slag	2.59	1.18	54.55

which decreased porosity and increased saturation degree (Yin et al., 2012). In addition, this process is a useful management strategy to mitigate slag pollution. The physical properties of the tailings and the slag are listed in Table 1. The true solid densities of the tailing and slag samples were determined using Eq. (1) on the basis of the specific gravity test results (Yesiller et al., 2014). The specific gravity (G_s) was measured using a water pycnometer based on the standard of ASTM D854.

$$\rho_s = G_s \rho_w \qquad (1)$$

where G_s is specific gravity of dry tailing or slag, ρ_s is true solid density of dry tailing or slag, and ρ_w is the density of water at 20 °C.

The bulk densities of the tailing and slag were determined as per standard GB/T 14684-2001 (6.14.2.3). A measuring cylinder was filled with a known mass of dry tailing or slag and covered with a rubber flat surface. The cylinder was tapped until there is no volume change of the tailing or slag. The bulk densities of the tailing and slag were referred to the ratio of the mass of the tailing or slag to the volume that it occupied in the cylinder (Abdullah and Geldart, 1999; Wong, 2002). The porosity (n) of the dry tailing or slag was estimated using Eq. (2).

$$n = \left(1 - \frac{\rho}{\rho_s}\right) \times 100\% \qquad (2)$$

where n is porosity, ρ is the bulk density of tailing or slag, and ρ_s is the true solid density.

Three tailing or slag samples were analyzed for the true solid density and bulk density determination to ensure the repeatability of the results. The data given in Table 1 represent an average value of these three test results. It also should be noted that the tailing or slag samples were dried using an oven at 105 ± 5 °C for 24 h before these physical properties were determined as per standard ASTM D2216.

A mineralogical analysis was performed on the micronized tailings or slag via X-ray diffraction. The tailings and slag specimens for XRD analysis were ground to the powders that all particle size were finer than 80 μm. The analysis technique and procedure of tailings or slag are similar as that of CPB samples, which will be given in Section 2.3.4. The chemical properties of the tailings and the slag are shown in Table 2. The main compositions of the tailings and the slag (e.g., CaO, MgO, and SiO_2) have a relatively positive effect on coagulation and strength development. Thus, the tailings and the slag do not delay CPB coagulation in Chihong mine.

Fig. 1 presents the particle size distribution (PSD) of the slag, the tailings, and the three types of cements. The PSD of the tailings and the cements were determined by using a Malvern Laser Mastersizer 2000 (Malvern Instruments, Ltd., Worcestershire, UK), which measures particles between 0.05 μm and 880 μm with an accuracy of ±1%. Moreover, the PSD of the slag was determined through artificial sieving.

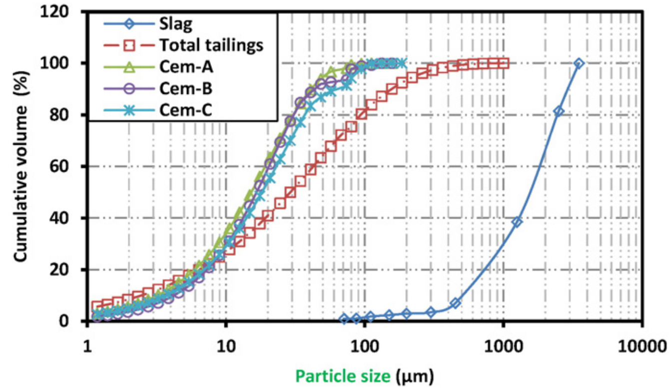

Fig. 1. The PSD curves of the water-quenched slag, the tailings, and the cements (Cem-A, Cem-B, and Cem-C).

2.1.2. Cements

Three types of ordinary Portland cement were used in the research. These cements were from the Zheba, Dianbei, and Zhaotong cement companies, which were located near Chihong mine. The three cements were labeled as Cem-A, Cem-B, and Cem-C, respectively. Cem-C is the cement that is currently used for CPB operations in Chihong mine. The PSD of the three cements are shown in Fig. 1. Moreover, tests on the other properties (e.g., coagulation, UCS) of the three cements were performed. The results are presented in later sections.

2.1.3. Mixing water

Tailings pore water (Por-W) and distilled water (Dis-W) were used as the mixing water for the experiment. Por-W was derived from Chihong tailings slurry by using a deep cone thickener. Por-W was used to make a paste with Cem-A, Cem-B, and Cem-C1. Dis-W was used to make a paste with only Cem-C2, since the Cem-C is the currently used binder in Chihong mine. The chemical analysis of Por-W via inductively coupled plasma–atomic emission spectroscopy is presented in Table 2. The analysis results show that Por-W contains a high level of Ca (717.2 mg/L), which presumably results from the addition of lime to control pH during mineral processing.

2.2. Mixing procedures

Four CPB samples with a constant cement content of 8.89%, a water–cement (w/c) ratio of 2.25, a slag–cement (s/c) ratio of 1, and the same tailings type were prepared, as illustrated in Table 3. The four samples were labeled as CPB-A, CPB-B, CPB-C1, and CPB-C2. The samples were mixed and homogenized using a Eurodib B20F mixer (3 speeds — 106/180/367 r/min) for approximately 8 min to produce the desired CPB mixture. It should be noted that the speed of mixer is about 106 r/min at the first 2 min and 180 r/min at the latter 6 min. This is to avoid the water and powder tailings splashing from the chamber at the beginning due to the centrifugal effect.

Table 2
Chemical compositions or elements of the tailings, the granulated slag, and the Por-W.

Tailings and slag	Compound	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	S	Loss-on-ignition	Total
	Tailings (%)	2.79	4.55	1.04	44.05	5.02	0.60	38.59	96.64
	Slag (%)	34.84	33.14	7.15	15.26	3.98	0.21	–	94.58
Por-W	Element	Cu	Pb	Zn	Mg	Ca	NO_3^-	Cl^-	–
	Content (mg/L)	<0.020	0.284	2.850	45.980	717.200	2.155	12.815	–