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Strength and ultrasonic properties of cemented paste backfill

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ABSTRACT

This paper presents the strength (UCS) and ultrasonic pulse velocity (UPV) properties of cemented paste backfill (CPB) produced from two different mill tailings (Tailings T1 and T2). A total of 240 CPB samples with diameter × height of 5 × 10 cm and 10 × 20 cm prepared at different binder dosages (5–7 wt.%) and water-to-cement ratios (3.97–5.10) were subjected to the UPV and UCS tests at 7, 14, 28 and 56-days of curing periods. UCS and UPV of CPB samples increased with increasing the binder dosage and reducing the *w*/*c* ratio irrespective of the sample size and tailings type. CPB samples with a diameter × height of 5 × 10 cm were observed to produce consistently higher (up to 1.69-fold) UCSs than those of 10 × 20 cm CPB samples at all binder dosages and *w*/*c* ratios. However, at the corresponding binder dosages and *w*/*c* ratios, the maximum variation of UPV between the CPB samples of 5 × 10 cm and 10 × 20 cm was only 7.45%. Using the method of least squares regression, the UCS values were correlated with the UPV values for CPB samples of 10 × 20 cm in size. A linear relation with a high correlation coefficient appeared to exist between the UCS and UPV for CPB samples. These findings suggest that the UPV is essentially independent of the sample size. In this regard, the UPV test can be suitably exploited for the rapid estimation of the strength and quality of CPB samples even using small samples with concomitant benefits of reducing sample size.

1. Introduction

Cemented paste backfill (CPB) is an engineered mixture of mill tailings (75–85% solids by weight), a hydraulic binder (2–9% by dry total paste weight) and mixing water. Each component of CPB plays a significant role on its short- and long-term performance (i.e., strength and stability), its transportation and placement to underground openings [1–3]. The mechanical strength of CPB at a given time is one of the most important quality criteria since the CPB structure must remain stable during the extraction of adjacent stopes to ensure the safety of the mine workers and to avoid ore dilution. In practice, the unconfined compressive strength (UCS) test is performed to determine the strength properties of CPB as the test is inexpensive and can be incorporated into routine quality control programs at the mine [4]. It is generally accepted that UCSs for rock, concrete and CPB design are obtained from cylindrical samples with a height to diameter ratio of 2:1 [5]. The cylindrical specimens with 10 × 20 cm in size are generally used in the assessment of mechanical performance of CPB [6–17]. In recent years; some researchers [18–20] have also used the CPB samples of 5 × 10 cm in size, which maintains the height to diameter ratio of 2:1 and reduces the tailings material to be used in the tests.

The sample size can affect the mechanical strength of rock and cemented materials (i.e., concrete and backfill). It has been reported that there is a reduction in strength with increasing sample size due to the increased probability of the number of microcracks in rock grains [21,22]. Darlington et al. [5] investigated the effect of sample size on the strength of cemented mortars. They showed that cylindrical mortar samples with a dimension of 6.35 × 12.7 cm produced approximately 10% higher strengths than those of 8.35 × 16.7 cm samples at 28 days of curing period. Felekoglu and Türkel [23] explored the effect of sample size using two different dimensions (10 × 20 cm and 15 × 30 cm) on the strength of normal and high strength concrete. They reported that the UCS values increased with increasing the sample size, which was claimed to be caused by wall effect. Hassani et al. [24] tested the size effect on the strength of three types of backfill; one blended tailings/sand fill, a composite-aggregate paste fill (CAP) and rock fill using cylindrical samples having different diameters. They indicated that the UCSs of rock fill decreased with increasing the sample size. As for the blended tailings/sand fill, they exhibited an increase in strength up to 15.2 cm size (diameter), but the strength subsequently decreased with increasing sample size. The CAP specimens showed negligible scale effects. Similarly, Revell [25] investigated the effect of sample size using cylinders with a height to diameter ratio of 2, (i.e., $D \times H$: 10 × 20 cm and 4 × 8 cm) on the strength of CPB prepared at 6 wt.% binder dosage over a

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curing period of 7 and 28 days. The investigator found that the small (4 × 8 cm) CPB samples produced consistently higher strengths (by 1.06–1.10-fold at 7 and 28 days) than those of the large (10 × 20 cm) samples.

Ultrasonic techniques, known as non-destructive and easy to apply both for site and laboratory conditions, are commonly used for estimating concrete or rock strength through ultrasonic pulse velocity (UPV) measurement [26–29]. The UPV test method employs the principle of measuring the travel velocity of ultrasonic pulses through a material medium. This method can be used as a means of quality control of products, which are supposed to be made of similar concrete [27]. CPB is a cementitious composite, like concrete, with similarities in terms of mix designs, rheology, material evaluation and transportation. Diezd'Aux [30] monitored the P- and S-waves velocity changes in CPB having 3–5 wt.% binder content between 1 and 3 days. He reported that evaluation of ultrasonic properties should be performed only after several days due to the inaccurate results in the short term. Galaa et al. [31] also measured the P- and S-waves in CPB samples (5 × 10 cm) containing 3% and 5% Portland cement, over one week period after mixing to understand the development of strength and stiffness in CPB (they did not correlate the UCS of CPB with UPV). Although UPV measurement is known to be extensively exploited for estimating the strength of concrete [27,29,32,33] and rock [26,28], there are no studies on the utilization of UPV measurement for estimating the strength of CPB.

In this study, the strength and ultrasonic properties of CPB produced from two different mill tailings was investigated using blast furnace slag cement as binder. CPB samples in two different dimensions, 5 × 10 cm and 10 × 20 cm were prepared at different binder dosages and water-to-cement ratios and subjected to UPV and UCS tests over 7–56 days of curing periods. The UPV and UCS results obtained from CPB samples having different dimensions (5 × 10 cm vs. 10 × 20 cm) were compared to understand the effect of sample size on the strength and ultrasonic properties of CPB. The UCSs of CPB samples (10 × 20 cm) were correlated with UPV results in an attempt to use the UPV measurement to predict the strength of CPB samples with different dimensions.

2. Materials and methods

2.1. Tailings and binders

Two different tailings samples (Tailings T1 and T2) obtained from Kastamonu–Küre copper plant located in the northwest of Turkey were used in this study. Following sampling, the physical, chemical and mineralogical characterizations of the tailings were determined (Table 1 and Fig. 1). Fines (<20 μm) content of the Tailings T1 and T2 were determined to be 45 and 48 wt.%, higher than the threshold level of 15 wt.%, which is required to form a paste (Fig. 2). These data suggest that Tailings T1 and T2 can be classified as medium size tailings according to Landriault [34]. The chemical analysis determined by XRF and ICP-AES indicated the high sulfide content of both tailings samples (Table 1). This was consistent with the results of mineralogical analysis using XRD showing that pyrite was the major sulfide phase in the tailings samples (Fig. 1). In addition to pyrite, quartz, calcite, albite and chlorite, silicate such as muscovite was also identified in Tailings T1.

Table 1
Physical properties and chemical composition of the tailings and binder used in the tests.

Characteristics	Tailings T1 (%)	Tailings T2 (%)	CEM III/A 42.5 R (%)
Chemical composition			
SiO_2	19.83	31.68	27.58
Al_2O_3	5.59	9.13	7.04
Fe_2O_3	45.43	33.06	2.37
MgO	2.30	3.99	3.91
CaO	2.20	3.50	52.75
Na_2O	0.36	0.79	0.25
K_2O	0.29	0.38	1.06
TiO_2	0.39	0.67	0.40
P_2O_5	0.03	<0.01	0.03
MnO	0.07	0.08	1.00
Cr_2O_3	0.023	0.035	0.015
Loss-on-ignition (LOI)	22.7	16.0	2.8
Total	99.21	99.33	99.21
Sulfide content (S^{-2}) (%)	29.12	16.88	–
Pyrite content (FeS_2) (%)	54.60	31.65	–
Physical properties			
Specific gravity (g/cm^3)	3.87	3.37	3.08
Specific surface area (cm^2/g)	3110	4440	

Blast furnace slag cement (CEM III/A 42.5N) was used as the binder in this study. The chemical composition and physical properties of the cement are summarized in Table 1. It should be noted that CEM III/A 42.5N contains granulated blast furnace slag (35%) as additive to increase the strength and stability, and to reduce the binder costs.

2.2. Preparation of CPB samples

A total of 240 CPB samples in triplicate were prepared by mixing and homogenizing the tailings samples (T1 and T2), binder and tap water in a Univex Stand model blender equipped with a double spiral (Fig. 3a). The solids contents of paste mixtures were set to

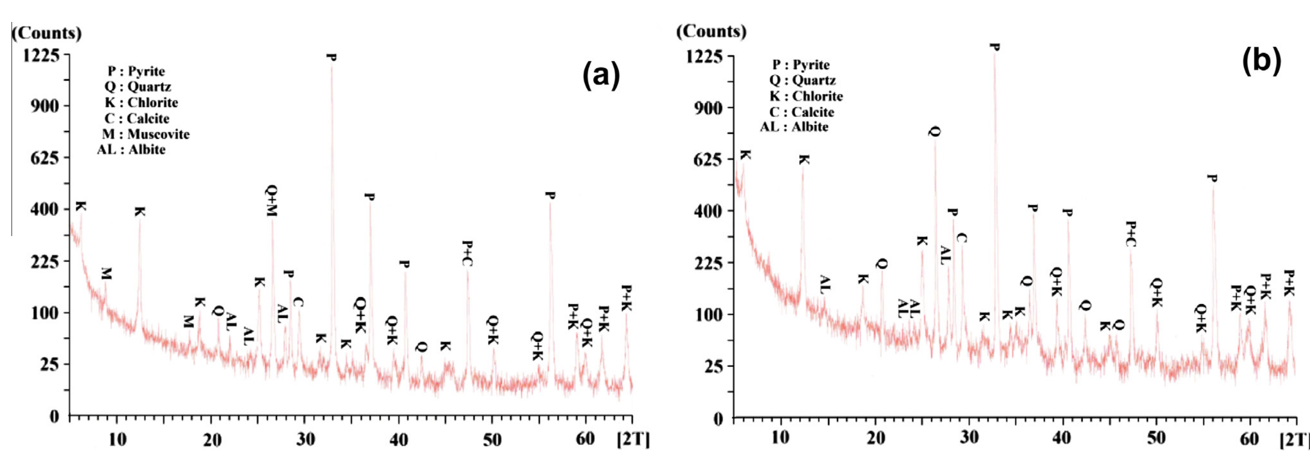

Fig. 1. XRD profiles of the tailings samples, Tailings T1 (a) and T2 (b).