Construction and Building Materials xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study on the rheological behavior of ultra-fine cemented backfill

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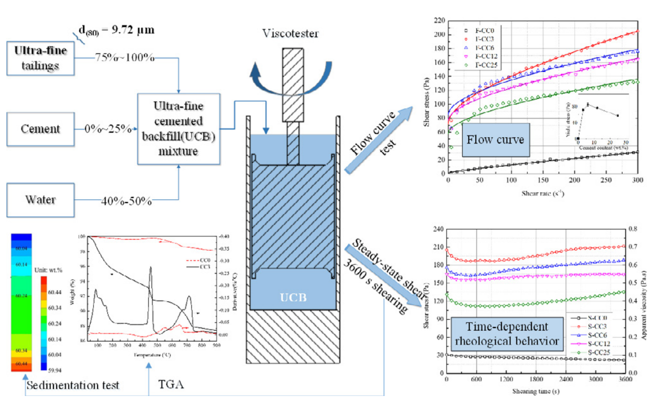
HIGHLIGHTS

- Ultra-fine cemented backfill (UCB) composited by cement and tailing with $d_{(80)} < 10\ \mu m$.
- Both thixotropy and rheopexy of cement contained UCB were observed.
- Only thixotropy of UCB without cement was found.
- At high shear rates ($\geq 25\ s^{-1}$), apparent viscosity decreased then increased.
- At low shear rates ($\leq 5\ s^{-1}$), viscosity increased before behaving like at high rates.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 October 2016
Received in revised form 26 April 2017
Accepted 6 May 2017
Available online xxxx

Keywords:
Ultra-fine cemented backfill
Ultra-fine tailings
Rheological behavior
Time-dependent
Solids concentration profile
Thermogravimetry

ABSTRACT

Ultra-fine cemented backfill (UCB) materials display distinctive rheological characteristics. This paper examines the rheological behaviors of UCB composited with cement and tailings that have a 80% cumulative passing size ($d_{(80)}$) of 9.72 μm. The findings were that UCB samples exhibit time-dependent non-Newtonian behaviors with a shear thinning characteristic, and both thixotropy and rheopexy properties are observed under long periods of steady-state shearing ($300\ s^{-1}$ shear rate). The results indicate that samples sheared at higher rates display lower apparent viscosities compared to the samples sheared at lower rates. At low shear rates ($\leq 0.5\ s^{-1}$), apparent viscosity increased until it reached a local peak (or two peaks) before behaving similarly to samples tested at higher shear rates. It was also found that the apparent viscosity of UCB increased consistently as the solids content was increased. Moreover, as cement content was increased, the apparent viscosity rose until it reached a peak at a cement content of 6%. The results also confirmed effects of solids concentration profiles changing over time and the cement hydration on the rheological behavior of UCB.

1. Introduction

Mining operations around the world have seen an increased demand for action and responsibility in the areas of safety and sustainability [1,2], and one of the methods being used by underground mines in meeting these demands is cemented backfill

Abbreviations: UCB, ultra-fine cemented backfill; CB, cemented backfill; UST, ultra-fine simulated tailings.

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http://dx.doi.org/10.1016/j.conbuildmat.2017.05.085
0950-0618/

Please cite this article in press as: X. Deng et al., Experimental study on the rheological behavior of ultra-fine cemented backfill, Constr. Build. Mater. (2017), http://dx.doi.org/10.1016/j.conbuildmat.2017.05.085

(CB) technology [3–6]. CB consists of a mixture of mine waste materials such as tailings, fly ash and slags, binder material, and water [7,8]. Generally, CB is prepared in a backfill plant located at the surface of a mine and is transported underground to mine stopes by pumps through pipelines [9]. The transportability of CB is a key performance property in its application, and the time dependent rheological behavior of CB is one of the most significant factors influencing transportability. Rheological properties do not only affect transport but also have a significant impact on pipeline wear [10,11].

As deposits become increasingly scarce it is becoming common for lower-grade ores to be targeted for extraction. These low grade ores are more resource and energy intensive to process, and using ultra-fine grinding and classification becomes necessary to achieve the adequate mineral liberation and recovery [12,13]. The ultra-fine grinding process contributes directly to the accumulation of an alarmingly large volume of ultra-fine tailings that have an 80% cumulative passing particle size ($d_{(80)}$) under 10 μm, and this material requires safe containment [14]. These ultra-fine tailings can potentially be used as one of the ingredients of ultra-fine cemented backfill (UCB), and the UCB can be used not only for underground backfilling mining but also for ultra-fine tailings disposal.

There have been a number of studies performed that explore the effects of fine particles on the rheological behaviors of fresh CB, slurry, cement paste, and minerals suspensions. The fine particles in CB samples which are in the size fraction of less than 20 μm, seem to have the most profound effect on CB's rheological behavior. The fines particles provide the water retention properties needed to prevent water bleeding, segregation of larger particles in the backfill, and act as a lubricant during CB transportation [15]. The effect of particle size on the rheological properties of grinding slurries, or dense aggregated suspensions, at various solids concentrations (up to 45 wt%) were reported [16–18]. Fine materials such as fly ash, silica fume, and biochar were considered as an admixture to modify the rheological behavior of cement paste [19–22]. It was found that finer particles have lower flow resistance and torque viscosity in the mixtures of high-performance concrete compared to larger particle sizes, and the finer particles may have a strong tendency for multi-layer adsorption of superplasticizer molecules [23]. The effects of fines proportion on the rheological and mechanical properties of CB were presented by M. Fall [24], who used slump tests to measure rheological behavior. However, these studies focused on fines with a $d_{(80)}$ particle size around 20 μm and did not present any specific research on the rheological properties of UCB with a $d_{(80)}$ under 10 μm. Ultra-fine materials have unique qualities, such as a large surface area to volume ratio, and understanding how these qualities influence the rheological behavior of UCB is helpful to optimize UCB application.

This paper is a focused experimental study of the basic and time-dependent rheological behaviors of UCB. The experiments were conducted using different solids contents, cement contents, shear rates and curing times. The typical flow curves of UCB, and the yield stress and apparent viscosity as a function of shearing time, are presented and analyzed. In addition to the rheology tests, the changes in solids concentration profiles over time and the microstructures of UCB were analyzed to study the effects of both sedimentation and cement hydration on the rheological properties of UCB. The results presented in this paper are part of a larger study to investigate the effects of rheology on wear in minefill distribution systems.

2. Materials and methods

2.1. Materials

2.1.1. Binder

The binder used in the preparation of the UCB mixtures was Portland cement (type GU) which was obtained from Basalite, Vancouver, Canada. Its chemical composition and physical properties are reported in Table 1. The $d_{(50)}$ and $d_{(80)}$ values of this cement are 17.9 μm and 29.7 μm respectively. The particle size distribution of this cement is shown in Fig. 1.

Table 1
Chemical composition and physical properties of GU Portland cement.

Chemical composition (%)		Physical properties	
C_3S	62	Specific Gravity	3.15
C_2S	12		
C_3A	7	Percent Soluble	<1%
C_4AF	10		
Gypsum	3	Specific surface area	0.846 m^2/g
Equivalent Alkalies	0.53		

2.1.2. Ultra-fine simulated tailings

An ore sample was obtained from the Mt. Polley mine located near Likely, British Columbia, Canada. Mt. Polley is a copper gold operation that mines roughly 20,000 tonnes daily with an average feed grade of 0.417 g/t Au and 0.3% Cu, and produces approximately 35 million pounds of copper and 45,000 ounces of gold each year [25]. A 20 kg sub-sample with a feed size of −50.8 mm was split, crushed using gyratory and cone crushers, and then ground using a rod mill to a $d_{(80)}$ of 150 μm. The chemical composition and mineralogy of the sample are shown in Tables 2 and 3. As shown in Table 2, the Cu grade is very low so it can be used to simulate tailings.

Samples of ultra-fine simulated tailings (UST) were prepared using a Netzsch LME4 horizontal stirred mill. The IsaMill is a high speed stirred mill that was developed by Mount Isa Mines in Australia for the economical grinding of minerals to fine and ultra-fine sizes [26]. The −150 μm Mt Polley ore sample was treated using the stirred mill under the following conditions: 1500 rpm, and 80% charge volume. Ceramic balls, Keramax MT1 (2 mm) were used as grinding media. After grinding, all the UST samples were collected, decanted, thoroughly mixed, and split to ensure they were homogeneous prior to the commencement of testing. The particle size distribution of each UST sample was measured by using the Malvern Mastersizer 2000 Laser Diffraction Particle Size Analyser, and the measurement results are presented in Fig. 1. The $d_{(50)}$ and $d_{(80)}$ values are 4.36 μm and 9.72 μm respectively. The specific gravity of tailings is 2.67 and the specific surface area is 2.47 m^2/g.

2.1.3. Water

Distilled water was used to mix the binder with the UST. The amounts of water were calculated and measured to obtain UCB mixtures with the desired consistency.

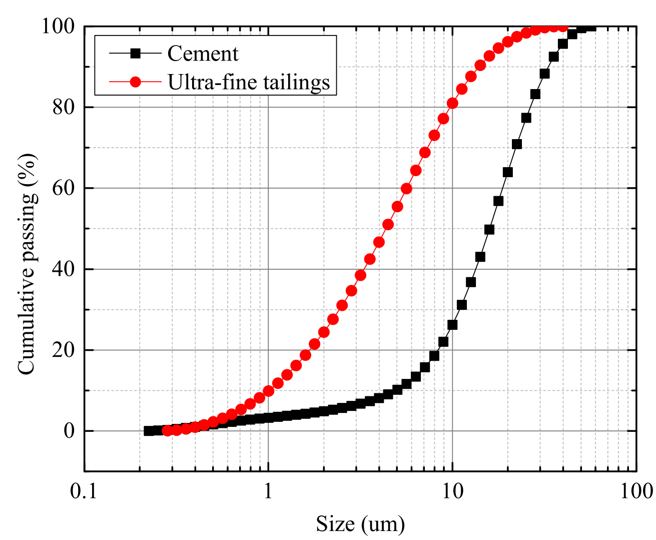

Fig. 1. Particle size distribution of cement and UST.

Table 2
Chemical composition of the Mt Polley ore sample.

Element	Cu	Fe	S	Ca	P	Mg	Ti	Al	Na	K
Percentage (wt%)	0.18	5.31	0.12	1.68	0.12	1.03	0.13	1.82	0.27	0.27

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