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Influence of binder content on temperature and internal strain evolution of early age cemented tailings backfill

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HIGHLIGHTS

- The FBGs were used to measure CTB temperature and internal strain evolution.
- In the liquid stage, the binder content had no effect on settlement behavior.
- CTB internal strain was influenced by combined chemical and thermal effects.
- No significant change occurred in settlement and strain in the hardened stage.

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ABSTRACT

The philosophy of the use of backfill is to return much of tailings waste to underground voids and increase working place stability to safely extract more minerals. The key issue for the safe and efficient design of cemented tailings backfill (CTB) structure is its mechanical properties and interaction with the surrounding rock. As a cemented material, CTB's strength is a function of hydration degree. As hydration is an exothermic reaction and results in net volume reduction, thermal expansion and chemical shrinkage occur simultaneously in the mixture. Each CTB component plays a significant role during this process and the most important factor is the binder content, because it influences the amount of cement hydration products that provide binding phases between tailing particles. In this paper, a number of fiber Bragg gratings (FBGs) were directly embedded into the 7-day cured CTB specimens to measure their temperature and internal strain evolution, with settlement development measured by Linear Variable Differential Transformer (LVDT). The experimental results showed that binder content had a significant effect on CTB temperature and internal strain evolution. Furthermore, the evolution of internal strain and settlement was an indicator of the transformation in different stages (such as fluid, skeleton formation and hardening) during the hydration process.

1. Introduction

In recent decades, cemented tailings backfill (CTB) has been widely used in most modern mines around the world [1–4]. The aim is to increase the mine productivity, reduce the surface tailings volume and other relative environmental issues and to contribute to mine operation safety [5–8]. CTB can be described as a complex composite composed of filtered tailings, water and binders (usu. 3–10% by solid weight) and typically contains 70% and 85% solids.

Once backfill is placed into a mined-out space of an underground mine, its mechanical properties are considered a key factor for backfill design. The desired CTB mechanical properties vary with the specific application or function. For example, the required CTB unconfined compressive strength (UCS) is 150–300 kPa when it is used for underground disposal [9]. In open stoping operations, mechanical strength higher than 1000 kPa at 28 d are needed to retain its self-supporting condition and minimize dilution risk [10]. When CTB is used as a support pillar, a UCS of higher than 4000 kPa is required [11]. Many studies have been conducted to classify the main factors that influence on CTB mechanical performance into two categories, i.e. intrinsic and extrinsic factors [1,7]. Intrinsic factors are associated with all parameters related to three main backfill components, tailings, water, binder, and their

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interactions during curing, including binder type and content, tailing chemistry (sulphate effects), particle size distribution, and water content [1,9,12–14]. As a cemented material, CTB strength is a function of hydration degree [15]. The hydration process can provide significant binding forces between the particles, refine pore structure, and result in the development of negative pore-water pressure (suction), which together lead to CTB strength gain. The above factors strongly influence the hydration process and thus play a key role in CTB strength development. Among these factors, binder type and content are fundamentally important for the hydration process and therefore critical to CTB mechanical properties. The binder used in CTB preparation provides hydraulic reagents, which react with water to impart CTB chemical stabilization and physical solidification [16]. In addition, a major reason that invokes interest in binder content is the expense of the cement, as binder costs can represent up to 75% of backfilling cost [17].

It is well known that hydration is an exothermic reaction, releasing heat and causing CTB temperature to rise. As a result, expansion occurs in the matrix at the same time due to temperature rise. Moreover, cement hydration leads to a net volume reduction, because the cement product volume is less than the sum of the water and cement volumes prior to hydration [18–20]. This volume reduction from cement hydration induces an internal volume reduction (chemical shrinkage) and external volume change (autogenous shrinkage). Hence, some studies have considered that settlement behavior of fresh cemented tailings backfill can be partially attributed to chemical shrinkage [21,22]. It means that the thermal expansion and chemical shrinkage both influence the internal strain evolution of CTB in the early cured period. Furthermore, although the volume reduction is small, it occurs together with increasing stiffness (or strength development) of the cementing matrix [20], and the induced well known "self-desiccation" process related to a significant reduction in pore-water pressure has been shown to be significant in controlling both short- and long-term backfill strengths [23,24]. However, most available results regarding the relationship between the hydration process and internal strain evolution have been performed for concrete [25–27]. As CTB is different from concrete with lower cement content, higher water to cement (w/c), and finer grain size [1,12,28], the water content or water/cement ratio (w/c) is important in chemical shrinkage [29,30], the above results thus might not be suitable for CTB.

Cement materials are also subject to other various types of shrinkage in addition to autogenous shrinkage, including drying, thermal and carbonation shrinkage [18]. Carbonation shrinkage is most considered in long-term behavior and will not be discussed in this paper. Drying shrinkage is an indicator of water loss, with the greater portion of drying shrinkage related to higher moisture loss [31], and hence, the magnitude of drying shrinkage in CTB is much greater than its autogenous shrinkage because there is more unbound water in CTB [22]. Thermal shrinkage is also dominated by the hydration process, while the ambient temperature showed no effects in this study.

As a porous cemented material, the CTB shrinkage phenomenon has been reported in some studies [20,22,32,33]. However, most studies have focused on drying shrinkage resulting from surface evaporation which can lead to microcrack development. Drying shrinkage is an indicator of physical variation (water content loss) while autogenous shrinkage is attributed to chemical and internal structural changes in cementitious materials. Monitoring drying shrinkage cannot reflect chemical reaction effects on shrinkage evolution. In addition, as drying shrinkage starts at the curing time of 6 d [22], technical data regarding earlier shrinkage evolution (autogenous shrinkage) within the CTBs is quite limited. Thus, it is necessary to substantially increase our knowledge regarding shrinkage evolution because of the binder hydration process during the early curing period.

CTB undergoes rigorous chemical reactions and phase transitions during the early-age. Paulini has recognized that hardening and strength growth begin at the point at which volume shrinkage appears [34]. His study considered internal strain as a hydration process indicator and to be related to the strength development. Therefore, in this study, a laboratory test was conducted to evaluate the temperature and internal strain evolution of 7 d cured CTB, as a result of the hydration process and phase transition. Fiber Bragg grating sensors were directly embedded into CTB specimens and because of their small size, they were non-invasive to the specimens [35–37]. Shrinkage and temperature changes were obtained simultaneously, immediately after casting and up to 7 d of age. In addition, settlement evolution was also simultaneously monitored using a linear variable differential transformer (LVDT).

2. Materials and methods

2.1. Materials

The materials used for the CTB preparation included binder, tailings, and water.

2.1.1. Tailings

Representative tailings material used in this study were obtained from the Xincheng Golden Mine's paste backfill plant (Shandong, China) after cyclone filtration processing. Classified tailings were used in this mine to prepare cemented hydraulic backfill because of its better performance in speeding up drainage and reducing the pressure on the barricades. Because the hydration process is dominated by tailings mineralogical composition [7,38], mine tailings samples were stored in sealed plastic containers to avoid any oxidation until their utilization for experimental tests. Natural tailings laboratory testing consisted of the determination of grain size distribution (GSD), solids specific gravity, specific surface area, and mineralogical and chemical compositions. GSD was analyzed using a Mastersizer2000 laser particle size analyzer (Malvern Panalytical B.V., Almelo, The Netherlands; Fig. 1). The physical properties of the examined tailings are tabulated in Table 1. Samples were featured with a coefficient of uniformity, Cu, of 2.24 and a coefficient of curvature, Cc, of 1.03. Based on the Unified Soil Classification System [39], the tailings sampled were identified as silty sand (SM). Tailings were mainly composed of biotite, plagioclase, quartz, chlorite, calcite, and labradoorite. Mineralogical analysis of the tailings was performed via an X-ray fluorescence spectrometer (Table 2).

2.1.2. Cement and water

In this study, Portland Cement Type I (PCI) was used as the binding agent, the main physical and chemical properties of PCI are presented in Table 2. Tap water was used to mix the tailings and binder, with Table 3 listing the main chemical composition of the tap water.

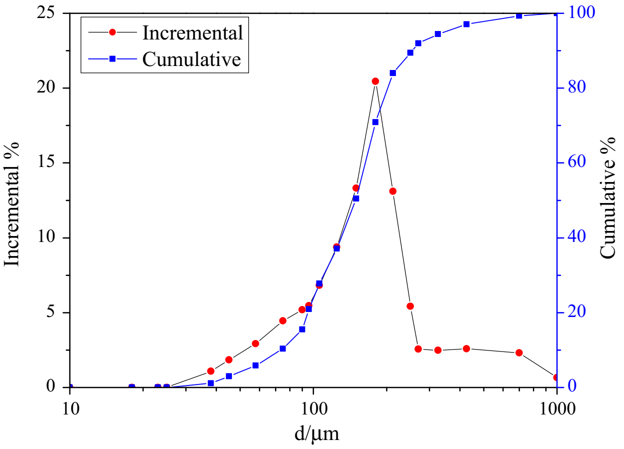

Fig. 1. Grain size distribution of the tailings used for the backfill material.