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Effect of superplasticizer type and dosage on fluidity and strength behavior of cemented tailings backfill with different solid contents

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HIGHLIGHTS

- The workability of cemented tailings backfill (CTB) are greatly affected by solid content, superplasticizer type and dosage.
- The best performance on fluidity behavior of fresh CTB mixtures are obtained from the naphthalene-based admixtures.
- The mechanical strength performance of CPB samples can be increased significantly by the superplasticizer added to the backfill mix.

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ABSTRACT

This paper presents the coupled effect of solid content and superplasticizer type and dosage on the fluidity and strength properties of cemented tailings backfills (CTB). A total of three different superplasticizers (namely, naphthalene, ether-based and ester-based polycarboxylate) were used at a ratio varying from 0% to 0.5% by mass of CTB. The CTB mixes were proportioned with a solid content of 65%, 66%, 68% and 70%. The unconfined compressive strength tests were performed on CTB samples after 3, 7 and 28 days of curing period. The obtained results show that the effect of superplasticizer on CTB performance depends on type and dosage of the superplasticizer used as well as solid content. The naphthalene-based polycarboxylate admixtures demonstrate the best improvement on fluidity behavior of fresh CTB mixture. For a given superplasticizer type, increases in the dosage of superplasticizer and decreases in the solid content lead to better workability of CTB samples. When increasing solid content, fresh CTB with high superplasticizer dosage performs a relatively low rate of decrease in the workability. A relatively high solid content and superplasticizer dosage have greatly contributed to improved mechanical strengths, especially at 28-day curing age, mainly due to a major reduction in water-to-cement ratio and porosity.

1. Introduction

Underground mining is widely used to remove and excavate valuable mineral resources from earth's crust, but it inevitably results in the production of large quantities of problematic tailings [1]. These problematic tailings generated by mineral processing are usually deposited in surface tailings impoundments or dams without any further steps due to its low cost [2]. According to statistics, more than 12,000 tailings dams with an alive storing capacity of higher than 100 million tons have been built across China [3]. Such disposal method poses a number of immense potential geotechnical (e.g., tailings dam failures, landslides and earthquakes) and environmental (e.g., acid mine drainage, heavy metal leaching and groundwater pollution) risks [4–6]. For example, a serious hazard caused by tailings dam failure happened in September 2008 in Shanxi Province China, causing 277 casualties and direct economic losses of $15 million [7,8]. With respect to the increasing number of tailings dam failures, it is urgently required to seek for a cost-effective and environmentally-acceptable tailings treatment/disposal method for mines. At present, mine backfill technology is the most innovative and practical way to deposit mine tailings safely, as it allows the voids or openings left from underground mining operations to be filled with tailings in the form of cemented tailings/paste backfill through pumps and pipelines [9–11].

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Additionally, the backfill technology has advantages of reducing the environmental impacts, supporting adjacent rock mass, controlling ground subsidence and favorable economics of mining [12–14]. Backfill is formulated from mill tailings generated from the mineral processing plant, hydraulic cement, and mixing water which is added to modify the ultimate slump consistency of the backfill.

In general, the backfill is expected to have a higher solid content (more than 70 wt%), which can improve its strength and stability, and then make it more endurable when extracting adjacent stopes [15–20]. However, an increase in the solid content usually leads to a reduction in the water content, which decreases the backfill's workability and may cause transportation system failures due to pipeline blockages [11,21,22]. Superplasticizers, considered as high-range water reducer, is often incorporated into the backfill mix in order to reduce water demand and thereby achieve higher solid content without eliminating consistency. So far, the superplasticizers used within the backfill can be classified into four families including lignosulfonate, sulfonated, naphthalene formaldehyde, sulfonated melamine formaldehyde, and polycarboxylate with a capacity to reduce the involved water content by 5–30% [23]. The main reason why superplasticizer can achieve the target workability with lower water content is that the superplasticizers are synthetic organics which act to disperse charged cement and tailings particles through electrostatic repulsive forces and steric hindrance forces [24–25]. Furthermore, the superplasticizer may have a positive impact on mechanical properties of backfill as shown by Erismann et al. [26]. The reason behind such high compressive strengths can be explained by microstructural improvement mainly due to reduced water-to-cement ratio in the studied mixture [10]. Several researchers have investigated the influence of superplasticizer on rheological and mechanical properties of laboratory-prepared mine backfills. They have demonstrated that the effect of superplasticizer on backfill performance is dependent on type and dosage of superplasticizer and binder as well as physical and chemical properties of tailings [23–25,27,28]. However, reports about the coupled effect of solid content and superplasticizers on quality and performance of CTB samples are scarce and also most of them are confidential works.

The originality of this paper consists in the comprehensive evaluation of the effect of superplasticizer and solid content on fluidity and strength behavior of CTB samples. Therefore, the main objective of this paper is to evaluate how these factors influence the quality and performance of CTB made of ordinary Portland cement (OPC). To achieve this goal, coarse size gold tailings were adopted to prepare various CTB mixtures with different solid contents, superplasticizer types and dosages. The fluidity values of fresh CTB mixes were tested by using a Mini-cone setup. Unconfined compressive tests at a predetermined curing times were conducted to evaluate the influence of solid content and superplasticizer on CTB's strength performance.

2. Materials and methods

2.1. Mine site description

The Canzhuang gold mine, located 30 km east of Zhaoyuan City, Shangdong Province, China, was commissioned in 1970s. The mine field is 1.70 km^2, and the mining depth is between elevation −950 m and 63 m. The mining and processing capacity are 300 tons per day and 400 tons per day respectively. The 2# orebody is the main orebody with an average horizontal thickness of 5.64 m and an inclination of 32°. The strike length of 2# body is around 210 m. A mechanized cut and fill method is used to extract gold ore from the underground mine deposit. The reasons why the Canzhuang gold mine uses the backfill technology can be explained as follows. Firstly, there are residential buildings and farmland above the mining area, and the ground surface is not allowed to subsidence for safety reasons. Secondly, the orebody and surrounding rock are weakened and broken with joints and faults. Moreover, around 130,000 m^3 tailings are deposited in tailings dams which cannot be expanded due to complex terrain. Therefore, using mine tailings to fill underground openings is an effective and practical method to reduce their environmental impacts and provide a safe underground working platform for mine operators. With the increase of mining depth and production capacity, the previous transportations system as shown in Fig. 1(a) cloud not meet the requirement of mining activity such as backfill strength and backfilling rate due to its outdated equipment and simple process. Therefore, an updated transportation system was built and has been well used since 2016 as illustrated in Fig. 1(b). A schematic view of the flow sheet of the Canzhuang gold mine studied is also shown in Fig. 1(c). Although the backfill technology has already been used in the Canzhuang gold mine successfully, further research of backfill is required to find ways to improve the workability, strength and stability of mine backfill and thereby reduce the backfill costs.

2.2. Tailings, binder and water

The tailings used in the study were sampled from the discharge point of the mineral processing plant at the Canzhuang gold mine. The tailings slurry was filled in plastic drums for natural sedimentation of five days, and then the top layer clear water was removed. The left sedimentation was dried in a drying box oven and then cooled naturally for preparing CTB samples. The drying tailings were homogenized to prepare a representative sample for determining their physical, chemical and mineralogical properties. The sampled tailings had an initial water content of around 25%, a bulk density of 1.214 g/cm^3, a solid specific gravity of 2.635, an apparent porosity of 53.93% and a void ratio of 1.17.

The particle size distribution of tailings was characterized by using a Malvern Mastersizer 2000 laser particle size analyzer and the obtained results are shown in Fig. 2. When $P_{D\mu m}$ represents the fraction of particle size smaller than the diameter, it is noticed from Fig. 2 that the tailings can be classified as a coarse size tailings material, as 27.52% by weight (wt%) of the sample is finer than the size of the ultra fine particles ($P_{20\mu m}$) [29]. The fine fraction of the tailings ($P_{80\mu m}$) sample is 48.42 wt%. The microstructural characterization of gold tailings was examined under a Zeiss (LEO) Scanning Electron Microscope (SEM) as illustrated in Fig. 4. It can be observed that the tailings have an irregular shape, a non-uniform particle size distribution and a relatively dense surface structure. The chemical composition of gold tailings was examined by Skyray X-ray Fluorescence and the results are listed in Table 1. The main chemical elements are silicon dioxide (69.55%), aluminum oxide (12.63%), potassium oxide (3.13%), and sodium oxide (1.98%), with smaller contents of ferric oxide (0.87%), calcium oxide (0.69%), sulfur trioxide (0.68%) and magnesium oxide (0.33%). The results are in good agreement with quantitative mineralogical analyses undertaken on micronized tailings sample by using X-ray diffraction (XRD), which specified the abundance of quartz, albite, sodalite and mullite (Fig. 3).

The function of the binding agent used within the backfill is to produce hydrated phases resulting in cohesion and strength. In addition, the binder enhances the lubrication of fresh backfill during the transportation process. OPC was chosen as the main binding agent in this study. OPC is a silica cement following the Chinese standard for "Common Portland Cement" (GB 175–2007). As listed in Table 1, the main components of OPC include calcium oxide (60.51%), silicon dioxide (22.86%), aluminum oxide (5.45%), ferric