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Research article

Utilization of phosphogypsum and phosphate tailings for cemented paste backfill

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A B S T R A C T

This research is an investigation of the feasibility of utilizing phosphogypsum (PG) and phosphate tailings (PTS) for cemented paste backfill. Some experiments were conducted with various combinations of PTS and PG as aggregates, along with slags and/or Portland cement as binders and CaO as an additive. The influence of the PG's ageing time on the consolidation of backfill was also explored. The unconfined compressive strength (UCS), the generated gases and the scanning electron microscope (SEM) were all tested and used in the analysis of backfill characteristics. The results show that (i) the highest UCS of backfill prepared by PG and PTS after curing for either 7 days or 28 days is still less than 1.0 MPa, with a large amount of CO_2 and SO_2 generated; (ii) the slags can improve the UCS by a factor of three, but not without a vast generation of CO_2, SO_2, and H_2S. However, the gases were not produced when CaO was added, but the UCS decreases suddenly to 0.2 or 0.4 MPa after curing for 7 days or 28 days, respectively; (iii) the UCS of backfill increases linearly with increasing cement content. When the CaO was added at 2%, the UCS reached 3.36 MPa after curing for 7 days and 4.44 MPa after curing for 28 days, and no gases were generated; (iv) the influence of the PG's ageing time on the UCS is negligible after 4 days of aging. Based on these results, it was concluded that PG and PTS can be utilized as backfill materials when Portland cement is used as a binder and CaO is used as an additive.

1. Introduction

Phosphogypsum (PG) is a problematic industrial by-product of the wet production of phosphoric fertilizer and acid. It is well known that the production quantity of PG is astonishing; 5 tons of PG will be produced per ton of phosphoric acid (Smadi et al., 1999; Tayibi et al., 2009). Global production of this waste is from 100 to 280 million tons per year (Perez-Lopez et al., 2016), but less than 15% of that is used as an agricultural fertilizer (Papastefanou et al., 2006; Abril et al., 2009), a soil stabilization additive (Ammar et al., 2016), and as a calcined material in the manufacturing of building products (Degirmenci, 2008; Singh, 2002). The other 85% is disposed of without further treatment, which can consume considerable land resources and cause serious environmental problems (Cuadri et al., 2014; Yang et al., 2015).

Phosphate tailings (PTS) are also an industrial waste with a yield of 20–30% of the crude ore from the production process of phosphate concentrate. Until recently, only approximately 5% of the PTS currently being produced can be utilized in Portland cement as a filler (Zheng et al., 2015), and the remainder is usually placed in a tailings dam without any environmental measures (Krekeler et al., 2008; Wang et al., 2008a). Apart from the more common problems such as floods, the occupation of precious land, etc. (Zeng et al., 1998; Chen et al., 2016), a PTS dam can cause terrible radioactive contamination due to the content of the natural radioactive nuclides U_{238} and Ra_{226} (Wetherill, 1983).

To promote the utilization of phosphogypsum, Li et al. (2008) and Wang et al. (2009) presented a novel and effective way to treat phosphogypsum in 2008: the PG was utilized for cemented paste backfill (CPB) and transported to the stope in a mine; this is known as PG backfill technology. Afterwards, Chen et al. (2010) developed a substitute for cement, the yellow phosphorus slags (hereafter referred to as ‘slags’), to bind the PG and form a high strength backfill. Additionally, Liao and Li (2010) observed that in some mines, the slags could not confer cementitious properties without CaO or NaOH as an additive. These achievements have

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accompanied a number of other advances such as excellent underground pressure control, improvement of ore production, and taken together, they provide a perfect disposal scenario for the PG in a phosphate mine. The previous studies were focused on how to make use of the most PG, but gave little attention to the utilization of PTS; however, they also provide a potential way to treat a mixture of the PG and PTS.

The Laohudong Phosphate Mine (LPM), Guizhou Province, China, is a phosphate mine and phosphorus chemical plant with a designed phosphorus ore production capacity of 2.6 million tons per year and a corresponding PTS yield of approximately 0.5 million tons per year. To prevent serious pollution to the environment and a potential security threat to the nearby village, the construction of a new tailings dam was banned by the Chinese government. Therefore, utilization of the PTS for CPB was proposed. Since the PTS yield is not high enough to be utilized as a backfill material on its own, a CPB technology with a mixture of PTS and PG as a backfill material was finally proposed in this mine. However, in the trial tests with different combinations of the PTS, PG and slags in the field, some problems, such as low strength, high settlement, and gas generation (sometimes it has a pungent smell), became evident and, although they may be common, they have not been discussed in the previous studies.

Therefore, based on the problems encountered in the LPM, this paper is an investigation of the feasibility of utilizing the PG and PTS for CPB technology. The physicochemical analysis of the various materials was carried out first; then, the unconfined compressive strength (UCS), the generated gases and the microstructural features (via scanning electron microscopy (SEM)) were tested for the analysis of backfill characteristics. Finally, the influence of the PG's ageing time on the consolidation was also explored.

2. Materials and methods

2.1. Materials

The materials used in this paper were PTS, PG, slags, and CaO, as shown in Fig. 1. The PTS utilized in this study were received from the mineral processing plant in LPM. The PG was collected from the fertilizer plant, which also belongs to LPM. Both of them were prepared and then tested in the School of Resources and Safety Engineering, Central South University (CSU), China. The slags from the smelting plant in LPM were tested by CINF Engineering Co., Ltd., China. The particle size distributions of the PTS, PG and slags are shown in Fig. 2. Tables 1 and 2 show the physical characteristics and elemental compositions of the GT and ST, respectively.

2.2. Methods

2.2.1. Experimental program

Many different combinations of materials were examined in this paper.

(1) The self-consolidation characteristics of the PTS and PG

The purpose of this combination was to observe the self-consolidation characteristics of the PTS and PG, and the backfill specimens were just produced with the PTS and PG, with no other binders or additives. Five groups of backfill specimens with PG-PTS ratios of 0:1, 1:3, 2:2, 3:1, and 1:0 were produced.

(2) The cementitious characteristics of the slags

The slags have been reported to be a good-to-perfect substitution in some mines, referring to the literature (Chen et al., 2010). Therefore, is it suitable to bind the PTS and PG in LPM? In this combination, the PG-PTS ratio was maintained at 1:3 (this ratio presented the best strength), and the slags-PTS ratios examined were 0.2, 0.4, 0.6, and 0.8.

(3) The cementitious characteristics of the cement

Because cement is the most effective binder widely utilized in all kinds of backfill applications (Wu et al., 2015; Wang et al., 2016),

Fig. 1. The materials used in this paper: (a) PTS; (b) PG; (c) slags; and (d) CaO.