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The effect of solid components on the rheological and mechanical properties of cemented paste backfill

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ABSTRACT

An experimental study is conducted to investigate the effect of solid components on the rheological and mechanical properties of cemented paste backfill (CPB). Based on the paste consistency, 78 wt.% could be a critical value for the solid contents. The mechanical strength increased proportionally with the increase of solid contents. The paste backfill samples prepared with 80 wt.% solid contents have a maximum unconfined compressive strength (UCS) of 7.26 MPa at a curing time of 28 days. A large binder proportion could weaken the consistency of the paste. The slump height drops from 27.5 to 23.5 cm when the bind proportions increase from 6.25 wt.% to 25 wt.%. The long-term mechanical performance increases significantly as the binder proportion increased. The UCS of the CPB sample with 8.33 wt.% binder is five times larger than the sample with 6.25 wt.% binder. A 25 wt.% addition of ungrounded slag causes the slump height to drop from 13 to 25.4 cm, mainly due to the decrease in the friction and void spaces between particles. However, the addition of coarse slag would weaken the mechanical properties of the CPB. The UCS of the samples without slag is almost two times larger than the UCS of the samples with 25% slag addition. The addition of soluble glass to the paste mixture appeared to improve the initial setting process. The initial setting time decreases from 846 to 108 min when the accelerator addition increases from 1.1 wt.% to 3.3 wt.%.

1. Introduction

Extractive operations usually co-produce large quantities of unmarketable materials. Tailings are the solid materials left over after the recoverable metals and minerals have been extracted from mined ore in a mine processing plant (Chan et al., 2008). They are commonly composed of finely ground host rock, gangue minerals, and a small amount of unrecovered ore minerals (Fall et al., 2010). Eighty years ago, it was not worth working copper containing less than 3% metal, whereas now ores with no more than 0.2% metal are worked. This results in a much greater yield and smaller size of tailings. The management of the aforementioned mine waste on the earth's surface is not only expensive but can also represent serious geotechnical (e.g., tailings dam failures) and environmental (e.g., acid mine drainage and groundwater pollution) hazards (Sharma and Al-Busaidi, 2001; Johnson and Younger, 2006). The tailings were usually disposed of by what has become known as the 'upstream method' due to its low cost. However, spillage and rainfall can make small gullies in the face slope. The base of these slopes becomes closer to the phreatic surface, and when the phreatic surface is too close to the slope, leakage begins from the base of these gullies, which soon enlarges to form a muddy flow.

Escalating costs and stricter regulations worldwide highlight the increasing need to reduce and re-use such wastes. An innovative tailings management technique, called cemented paste backfill (CPB), has become widely employed in hard rock underground mines for ground support purposes in most modern mines around the world (Daniel et al., 2011; Sivakugan et al., 2006). CPB operation consists of mixing tailings with a low proportion of hydraulic binders (3–7 wt.%) and a relatively high proportion of water (typically 25% water) and transporting the mixture into mine openings (Coussy et al., 2011). The paste backfill typically contains between 70% and 85% solids. This technology plays three important roles. First, it can be used as a construction material to create a floor, wall or roof/head cover for mining activities. Second, it is a major means of ground support, thereby providing a safe work environment. Finally, it provides an effective means of mine waste disposal. Paste backfill has been used in mines in Australia, Canada, Europe, and others, but it remains a relatively new technology in China.

In China, the quantity of tailings produced in the last few decades is estimated at approximately 500 million tons, and 100 million m^3 of underground voids are generated annually as a result of

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mining. Hundreds of thousands of tailing ponds are distributed all over the country, and dam failure disasters occur frequently. For example, on 8 September 2008, a tailing dam located in Shanxi Province collapsed, releasing a million tons of liquefied tailings on a nearby village while the inhabitants were asleep. The tailings travelled a distance of 2 km, and 277 people were killed. Concerned about the increasing number of tailings dam failures, the Chinese mining companies are seeking safer treatment methods for tailings. Chihong Mine was the first mine to use CPB technology to address the tailings.

Chihong Mine, located 270 km north of KunMing City, Yunnan Province, was commissioned in the 1950s. It is one of the largest mines in the world, with lead and zinc grades greater than 37%. The mine is also rich in germanium, silver, cadmium, and other rare metals. The deposit is a vertically oriented ore body lying under 600 m of overburden. The ore body is 10 m thick and 400 m wide and has a trend length of 1000 m. A mechanised cut-and-fill technique is used to extract lead and zinc ore. Gravity hydraulic fill with coarse particles has been used by ChiHong for the last 50 years. A total of 60 million tons of mill tailings and 100 million tons of smelt slag have been accumulated, and more than 3 million tons of tailing and smelt slag will be deposited annually. The deposition of these waste materials requires a lot of land and leads to serious environmental pollution. Meanwhile, the tailing ponds and smelt slag fields cannot be expanded due to the complex surrounding terrain. Because the mine is located near the Niulan River, the waste discharge is strictly controlled according to environmental protection laws. Thus, utilising the mineral waste as a filling material is one of the best methods to treat the unclassified tailing and smelt slag. In addition to the tailings disposal benefit, another important reason why ChiHong chose the paste filling technology is the deep mine activities. The mining depth has already reached 1200 m, and the stress conditions of the surrounding rocks are becoming more serious. Under the support of cemented paste, the ore pillars could be recovered to achieve a higher level of ore recovery and to reduce the ore dilution and loss rate. To recover as many metals as possible, the ores are ground into finer particles in a processing plant. The finer tailings were difficult to dewater and dry. Therefore, paste filling is the best choice for ChiHong Mine.

Although the paste filling technology has been applied successfully in ChiHong, low consistency, weak strength and delayed coagulation of the CPB are the challenges facing by this system. The purpose of this paper is to highlight the influence of the factors of tailings, binders and accelerators on the paste backfill strength acquisition. To reach this goal, mine tailings from ChiHong Mine were sampled for the preparation of different paste backfill mixtures using different solid contents, binder proportions, tailing/slag ratios, and accelerators. The mechanical behaviour of the samples was tested to reveal the effect of the solid components on the rheological and mechanical properties of the CPB.

2. Materials and methods

2.1. Tailings characteristics

Fig. 1 shows the cemented paste backfill plant of Chihong. Mill tailings from the processing plant and slag discharged from smelt plant were the main components available in ChiHong, and ordinary Portland cement was chosen as a binder to give sufficient mechanical strength to the paste backfill created. The tailings are first fed to a high-capacity thickener to increase their solid percentage to approximately 78–81% by weight. To aid filtration, some flocculent is added. The thickened tailings are then pumped from the thickener to feed a spiral mixer, to which the cement and slag are added. The mixed paste is dropped into a pipe and transported to a stope using gravity.

Fig. 1. The cemented paste backfill system of Chihong Mine.

As shown in Table 1, the percentage of fine particles with a size smaller than 0.005 mm reaches 35.44%. The physical properties of the filling material are shown in Table 2. The specific surface area of the tailings is almost two times that of cement. The small size of the tailings slows the reaction between cement and water, which leads to poor coagulation of paste.

A mineralogical analysis was performed on the micronised tailings via X-ray diffraction. The chemical properties of the tailings and slag are shown in Table 3. Calcite is the main mineral in the tailings (52.47%). The other important minerals are dolomite (30.33%), sericite (6.57%), quartz (2.88%), pyrite (2.88%), limonite (1.59%), sphalerite (1.25%) and galena (0.53%). Calcite and dolomite, which had a relative positive effect on coagulation, are the major compounds in the tailings.

2.2. Granulated slags

The Chihong Mine has considerable quantities of slag available from lead/zinc smelting operations. The slag has been granulated to form a black sand-like material. The dumped slag would be another potential source of pollution, so the potential use of available granulated lead/zinc slag in CPB is taken into consideration. The particle size distribution of the slag is shown in Table 4; the slag is much coarser than the tailings. An increase in the particle size of the material may lead to an increase in the solid weight percentage, and this causes a decrease in porosity and an increase in the degree of saturation. The unground slag samples were blended in tailing/slag proportions of 100%/0% and 75%/25%.

2.3. Binders

The binders used in the preparation of cemented paste backfill mixtures can be defined as hydraulic reagents. These are anhydrous phases that are able to react with water (hydration) to form hydrated phases. The latter gives the paste backfill cohesion, i.e., strength that generally increases with time. The addition of the binder is essential to achieving the desired strength of the CPB (Brackebusch, 1994). The type and proportion of binder has a significant effect on the mechanical behaviour of paste backfill materials and even its resistance to deterioration. Therefore, the utilisation of suitable and cost-effective binders and the optimisation of the binder dosage are quite important in practice. Portland cement was used in this study. The relative density of the binder is 3.1. The main physical properties are shown in Table 2.