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Compressive behavior and microstructural properties of tailings polypropylene fibre-reinforced cemented paste backfill

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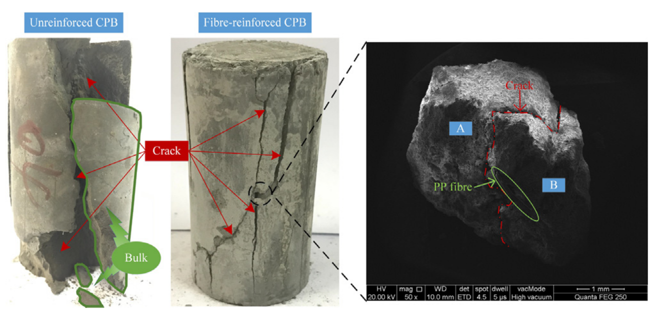
HIGHLIGHTS

- PP fibre can improve the UCS, stiffness, ductility and stability of CPB.
- Best fibre parameter levels are a fibre content of 0.15% and a fibre length of 6 mm.
- PP fibre bring much more improvement to the early strength of CPB.
- Fibre can bridge the cracks of CPB.

GRAPHICAL ABSTRACT



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ABSTRACT

This experimental study was carried out to investigate the influence of polypropylene (PP) fibre on the compressive behavior and microstructural properties of tailings (classified as CL – lean clay) cemented paste backfill (CPB). The compressive behavior was determined by the unconfined compressive strength (UCS), and structural changes in CPB were evaluated by macrostructural failure analysis and microstructural tests with scanning electron microscopy (SEM) analysis. Orthogonal tests were designed to research the influences and significance of the cement content, solid mass concentration, fibre content and fibre length on CPB. The results indicate that although the fibre parameters are not as significant as the cement content and solid mass concentration for CPB strength, they are also important factors for improving the UCS of CPB, and the effect of PP fibre on the early (3 days curing time) and later (28 days curing time) stage strength of the backfill is much more obvious than that on the medium stage (7 days curing time) strength. And fibre can enhance the stiffness and ductility of CPB with increasing strain and E_{50}. In addition, the fibre content is much more important than the fibre length, there is no linear relationship between UCS and the fibre parameters (fibre content and fibre length), and the best fibre parameter levels are a fibre content of 0.15% and a fibre length of 6 mm in this study. Moreover, macrostructural failure analysis and SEM microstructural tests indicated that PP fibre tend to bridge the cracks, which can reduce the porosity of the CPB matrix and improve its compactness, integrity and residual strength with some calcium silicate hydrate (C-S-H) gelling trapped on its surface.

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1. Introduction

Cemented paste backfill (CPB) is an important development direction of mine backfill techniques and an innovative mine tailings processing method that can reduce the environmental and safety problems caused by the accumulation of tailings [1–4]. CPB is composed of tailings, binding agent, water and other additives, and tailings is main filling aggregate. Research suggests that well-graded tailings can improve the consolidation performance and exhibit a good effect on the CPB strength [5,6]. However, backfill treatment of tailings with too much fine particles tailings is very difficult because of their unreasonable gradation, slow settling and other properties. The use of tailings alone can easily cause the problem of low strength, so in general, a very small proportion of tailings can be used in combination with coarse tailings to fill the pores of a CPB matrix [5]. Therefore, improving the utilization and strength of waste tailings has been a hot research topic.

For the past few decades, several types of fibres, including steel, polypropylene, glass and carbon fibres, have usually been used to improve the stability of structures and ductility of concrete in civil engineering and construction industry [7–12]. Based on their features of high tensile strength, good dispersivity and strong ductility, fibres can be effectively mixed in cement-based materials, restraining the initiation and propagation of cracks and improving the strength of the matrix [13]. Fibre was reported having beneficial effects on compression strength of concrete [14,15]. In addition, the well performance of fibre on the strain at peak stress and ductility index also were published [16,17]. Moreover, fibres also have wide applications in fibre-reinforced cemented sand and soil, and many experiments have been conducted to research the benefits of fibre-reinforced sand and soil [18–22]. Especially for fine soil, Cristelo et al. [9,13] indicated that the polypropylene (PP) fibre content and fibre length both affect the strength and stiffness, and the results showed that the post-cracking behavior is strongly affected by PP fibres. These studies have an important guiding role in this study.

In mining engineering, many researchers have also used fibres materials in the backfill and support measures field [23–27]. Their main purposes include the following: 1) reduce the overall cement usage and increase the utilization of tailings; 2) improve the stability of the structure; and 3) research the mechanical behavior of fibre-reinforced cement-based mining structures. And their results shown that the fibre can improve the compression strength of CPC. However, much work still needs to be done on fibre-reinforced CPB because the tailings properties and backfill requirements of different mines are usually different. Especially for tailings with too much fine particles due to the poor backfill performances of CPB which is hard to recycle.

Therefore, this experimental study on tailings CPB was carried out to investigate the influence of PP fibre on the compressive behavior of CPB, and orthogonal tests were designed to research the influences and significance of the cement content, solid mass concentration, fibre content and fibre length on CPB. Macrostructural failure analysis and microstructural tests by scanning electron microscopy (SEM) were used to study the crack development and structural changes of CPB.

2. Materials and methods

2.1. Material characterization

The Fan Kou lead–zinc mine, located in the northeastern Guangdong Province of China, provided all the tailings for this study. The tailings were collected in ore processing plants, stored in barrels and transferred to the lab of Central South University. Different tailings samples were then taken for tailings size distribution determination by an LS particle size analyzer (LS13320, Beckman, USA), chemical composition measurement using an X-ray fluorescence spectrometer (XRF) (ZSX Primusll Ⅱ, Rigaku Corporation, Japan) and mineralogical composition analysis with an X-ray diffractometer (XRD) (Ultima Ⅳ, Rigaku Corporation, Japan). Fig. 1 displays the particle size distribution of the tailings, and the results show that the mean particle size of the tailings is 39.30 μm. The tailings are medium with proportions of more than 47.15% for particles less than 20 μm in diameter [28]. Table 1 lists the chemical composition measurement results (XRF) of the tailings, from which one can observe that the content of SiO_2 is 27.10%, and the total content of main oxides (Al_2O_3, SiO_2, Fe_2O_3, MgO, and CaO) amounts to 81.98%. The XRD patterns (Fig. 2) show that the main mineralogical compositions of tailings are pyrite (FeS_2), muscovite [$(K,Na)(Al,Mg,Fe)_2(Si_{3.1}Al_{0.9})O_{10}(OH)_2$], dolomite [$CaMg(CO_3)_2$], silicon oxide ($SiO_2$) and calcium carbonate ($CaCO_3$). The XRD results are the same as the XRF results. The geotechnical characterization of tailings is summarized in Table 2, and based on these results, the tailings are classified as CL – lean clay [29]. The tailings have a bad gradation, and their osmotic coefficient is low, which is not conducive to the filtration of water.

Monofilament polypropylene (PP) fibres (C_3H_6) were used to reinforce the CPB, and Table 3 presents their main properties. These PP fibres have an average diameter of 19 μm, a density of 910 kg/m^3, good dispersion, very high acid and alkali resistance and null moisture absorption and toxicity. Also according to Table 3, these PP fibres have a fracture strength of greater than 350 MPa and an elastic modulus of greater than 3.5 GPa, which makes it possible to improve the mechanical properties of CPB by mixing it with PP fibre. Fig. 3 shows the shape of PP fibres of different lengths (3 mm, 6 mm, 9 mm, and 12 mm) used in this study. However, adding fibre will increase the cost of backfill. Therefore, the relatively small fibre contents in this study were 0.05%, 0.1%, 0.15% and 0.2% by mass of the sum of tailings and cement. Both the fibre length and content effect on the CPB will be tested.

Portland cement P.O 42.5R (where "R" stands for initial high strength cement, with a minimum compressive strength of 22.0 MPa and 42.5 MPa at 3 and 28 days, respectively) was used as the binder. The CPB specimens with 14%, 17%, 20% and 25% cement content by mass of tailings were tested to compare the contributions of cement to the mechanical properties of CPB. Moreover, to reproduce the site conditions as accurately as possible, the tap water was utilized to prepare all the test specimens.

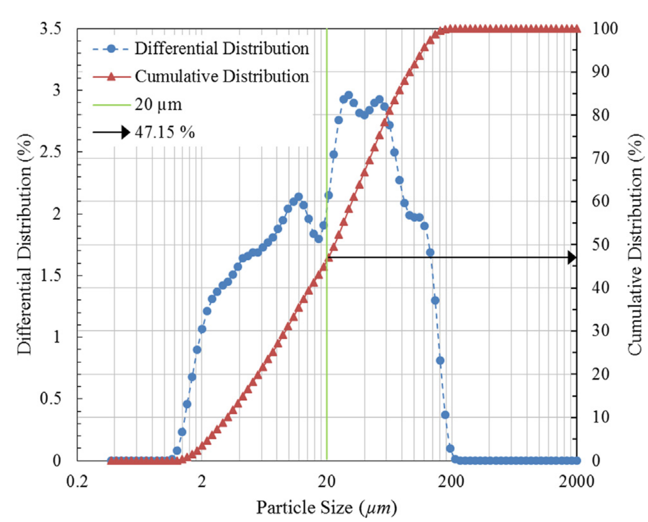

Fig. 1. Particle size distribution curve of tailings.