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Mechanical and thermal properties of cemented tailings materials at early ages: Influence of initial temperature, curing stress and drainage conditions

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HIGHLIGHTS

- Cemented paste backfill (CPB) is extensively used in underground mining as a construction material.
- Initial backfill temperature affects its thermal and mechanical properties.
- Curing stress affects the thermal and mechanical properties of CPB.
- Drainage conditions affects the thermal and mechanical properties of CPB.

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ABSTRACT

The cementitious construction material, cemented paste backfill (CPB), is extensively used in underground mining operations worldwide. After the CPB is placed in the field, the evolution of its mechanical and thermal properties strongly affects its stability and the heat transfer within it. An experimental setup is designed to enable the curing of CPB samples under different stresses, filling rates, initial temperatures and drainage conditions as well as the monitoring of the changes in capillary pressure, temperature, amount of drained water and electrical conductivity in the CPB samples during curing. Furthermore, extensive testing is carried to investigate the combined effects of initial temperature, curing stress and drainage on the mechanical, microstructural and thermal properties of CPB. The obtained results reveal that these properties are strongly influenced by the initial backfill temperature, curing stress and drainage conditions, and their interactions. These can significantly affect the cement hydration, capillary pressure development and pore structure of CPB.

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1. Introduction

During underground mining operations, large quantities of mine waste, such as tailings, are produced. However, the surface disposal of tailings is not only a significant expense, but may also give rise to potential long-term environmental issues, such as acid mine drainage (AMD) [1–4]. As an alternative to surface tailings disposal, cemented paste backfill (CPB), which comprises a mixture of tailings, binder and water, is an innovative cementitious material (however, CPB is different from concrete) used for underground mine backfilling and mine waste management [5,6]. CPB reduces the volume of surface tailings and other pertinent environmental issues when it is placed into the mined-out space of an underground mine, which is commonly known as stopes [7–9]. Moreover, CPB can also provide ground and wall support, limit the possibility of caving, and prevent subsidence [6,10,11]. Consequently, the application of CPB technology significantly improves safety in underground mine operations and increases productivity. Due to its environmental, financial and safety benefits for the mining industry, CPB technology is now regarded as a standard practice in mining operations worldwide [12,13]. Mechanical properties are considered to be a key factor for the safe and efficient design of CPB structures, such as the unconfined compressive strength (UCS), stress–strain behavior and shear strength parameters [2,14–16]. These properties are required to properly assess the mechanical stability of CPB, which must demonstrate acceptable mechanical properties to ensure the safety of miners. Moreover, early age mechanical properties are particularly important for the mechanical stability of backfill structures at the early ages, reduction in the liquefaction risks of CPB and the optimization of

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mining cycles by the early opening of the barricades, which are retaining walls built at the draw points of open stopes to contain the CPB when it is still fluid and/or very soft. Besides the mechanical properties, the thermal properties of CPB and in particular, the thermal conductivity, are critical for the assessment of the heat transfer between the CPB and its surrounding environment (rock mass, mine atmosphere), cement hydration induced temperature increase within the CPB structure, and thermal stress in the backfill structures.

Once placed in the field, the CPB structure is subjected to strong coupled thermal (T; e.g., temperature), hydraulic (H; e.g., suction, pore water pressure, degree of saturation, drainage), mechanical (M; e.g. stress, self-weight load) and chemical (C; e.g., pore water and cement chemistries) (THMC) processes or factors [2], as illustrated in Fig. 1. These factors and their interactions can significantly affect the mechanical and thermal properties of CPB.

Several studies have been performed in past years to investigate the mechanical and thermal properties of CPB and the factors that affect them [15,16–22]. However, most of the past studies have focussed on studying the isolated effect of one factor (T, H, M, or C) on the mechanical or thermal properties of CPB. Only a few studies have dealt with the coupled effects of the factors mentioned above that influence the properties of CPB [2,23]. However, no studies have addressed the effect of the initial temperatures of CPB on its mechanical and thermal properties. Furthermore, the investigation of the evolution of the thermal and mechanical properties of CPB with various initial temperatures and subjected to various drainage conditions and curing stresses have been so far neglected. There is therefore the need to address this knowledge gap for both economic reasons and the safety of mine workers. This is because fresh CPB can have varying initial temperatures, and the CPB can be subjected to various drainage (from undrained to drained) conditions (for example, CTB with low permeability and high cement content and fast filling rate can be subjected to undrained conditions, while a highly permeable CPB with low cement content that is surrounded by highly permeable rockmass can be subjected to drained conditions) and curing stresses in the field. The initial backfill temperature is strongly affected by the initial temperatures of the mix components (tailings, water) and the geographical location (e.g., warm/cold region) [19]. Furthermore, an increase of the temperature in fresh CPB can occur during its transport in pipes from the surface to the underground working areas of a production section as described by Wang, Fall and Wu [24]. Therefore, the objective of this study is to investigate the combined effects of initial temperature, curing stress and drainage condition on the evolution of the mechanical properties and thermal conductivity of CPB at the early ages (Fig. 1).

2. Materials and methods

2.1. Materials

2.1.1. Binder and mixing water

In this study, Portland Cement Type I (PCI) is used as the binding agent. Tap water was used as the mixing water for the CPB samples.

2.1.2. Tailings

Artificial non-acid-generating tailings (ground silica) were used in the preparation of the CPB mixture. Ground silica is essentially made of quartz, which is one of the dominant minerals in Canadian hard rock mines [6]. Compared with natural tailings which often contain sulfide minerals or other reactive minerals, the mineralogical and chemical compositions of ground silica tailings are controlled. Moreover, the chemical stability of quartz can further reduce the potential uncertainties induced by reactions between reactive tailings, water and air, which can affect the interpretation of the experimental results. In addition, with about 45% by weight of fine particles, the grain size distribution of the silica tailings is close to that of the average of natural tailings from 9 nine Canadian mines [25].

2.2. CPB sample preparation and mix proportions

In the mix recipe of the CPB samples, a weight proportion of 4.5% for PCI was adopted and the water to cement ratio (w/c) was set to 7.6. With the aid of a mortar mixer, the tailings, PCI and tap water were thoroughly mixed for 7 min. Afterwards, the fresh CPB mixture was placed into the pressure cells described below. In order to investigate the influence of initial temperature

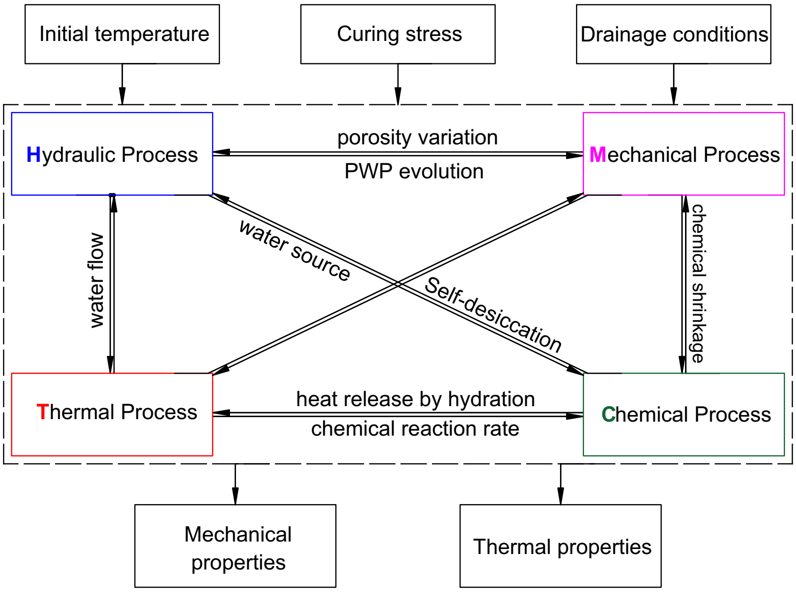

Fig. 1. Factors that affect mechanical and thermal properties of CPB and relationship with initial temperature, curing stress and drainage conditions (PWP: pore water pressure).

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