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Strength evolution and deformation behaviour of cemented paste backfill at early ages: Effect of curing stress, filling strategy and drainage

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ABSTRACT

In this study, a pressure cell apparatus is developed to investigate the early age evolution of the strength and deformation behaviour of cemented paste backfill (CPB) when subjected to various loading conditions under different curing scenarios. The different curing scenarios that are simulated include: (1) drained and undrained conditions, (2) different filling rates, (3) different filling sequences, and (4) different curing stresses. The findings show that drainage, curing stress, curing time and filling rate influence the mechanical and deformation behaviours of CPB materials. The coupled effects of consolidation, drainage and suction contribute to the strength development of drained CPB subjected to curing stress. On the other hand, particle rearrangement caused by the applied pressure and suction development due to self-desiccation plays a significant role in the strength gain of undrained CPB cured under stress. Furthermore, curing stress induces slightly faster rate of cement hydration, which can contribute to strength acquisition.

1. Introduction

Cemented paste backfilling is a technology widely used in mining operations to fill mine openings or stopes [1–3]. Cemented paste backfill (CPB) provides ground stability to mine stopes, improves ore recovery and also maintains a safe working environment for mine workers and mining equipment [4–8]. It also benefits the environment by reducing the amount of tailings required for deposition onto the earth surface [9].

CPB is a mixture of thickened tailings from the milling or processing of mines, hydraulic binders and a large volume of water. It is delivered to the underground by pumping and/or using gravity flow systems at a controlled consistency and filling rate [10,11]. Backfill material is used to provide a free-standing wall while the adjacent stope is mined out [12]. At the early ages, the backfill is held in place by retaining walls structures called barricades (or bulkheads) at the drawpoint drifts that access the mining stope prior to stope filling [4,13]. In most of the mines, a sequential filling strategy is implemented to fill up the mine voids, which consists of first pouring the plug fill (typically a CPB with higher cement content) up to 2–3 m (typically) above the drawpoint followed by curing time which can take up to a few days. Afterwards, the main pour (or residual fill) is poured to fill the rest of the mine stope [14,15]. This strategy contributes to maintaining low pore water pressure (PWP) and stress in the backfill and on the barricades.

The backfilling of underground mine voids by using CPB is a complex mining/geotechnical process. This complexity is mainly due to the fact that the properties and behaviour of CPB are controlled by several factors which are also interactive, which includes mechanical (M), thermal (T), hydraulic (H) and chemical (C) factors, as schematized in Fig. 1 [16–19]. Some key factors that play a critical role are curing stress (M factor), drainage and suction (H factor), curing temperature (T factor), filling rate and sequence (F factors) and cement hydration reactions (C factor) [18–21]. For example, curing temperature increases the rate of cement hydration reactions [22]. Higher self-desiccation due to the development of suction and drainage increases the mechanical strength [23]. These THMC factors and filling process (F) directly influence the key design criteria of paste backfill, such as the mechanical stability of CPB, as well as the mining plan and cycle time. Subsequently, this knowledge is utilized to determine the required cement content and slump [24,25].

The unconfined compressive strength (UCS) of CPB is the most frequent property used to assess the mechanical stability of CPB structures because UCS testing is relatively inexpensive and quick, and can be easily incorporated into routine quality control programs at the mine [2,22,26,27]. CPB must reach a certain UCS in a time period that allows the mining activities (blasting, hauling, etc.) to continue on schedule [24]. A mechanically stable CPB

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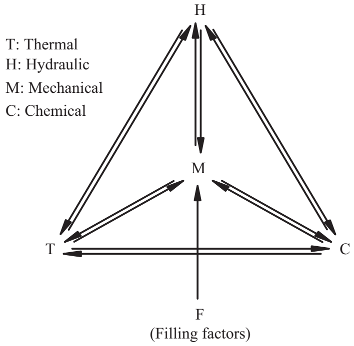

Fig. 1. THMC-F factors and their interactions in CPB material.

structure at the early ages is especially important for the opening of the barricades, thereby reducing the mining cycle time, and thus increasing mining efficiency and improving production [26]. Besides the UCS, in the ground support role, the deformation behaviour and stiffness (Young's modulus) of the CPB are also key design properties of major interest [22].

Despite the intensive and increasing use of cemented paste backfilling in mining operations, it remains a relatively new technology. Consequently, many fundamental aspects, such as the effects of curing stress, drainage and filling strategy (filling rate and sequence) and their interactions on the strength development and deformation behaviour of CPB at the early ages, are still not well understood. A literature review shows that there is still a paucity of information or data on the impact of the aforementioned factors and their interactions on the strength and deformation behaviour of CPB materials [28,29]. The limited information has been mainly attributed to the lack of adequate laboratory experimental setups which can enable the production and testing of CPB samples simultaneously, while subjected to various curing stresses and drainage conditions as well as various filling rates and sequences. This research gap has motivated the authors of this paper to develop a pressure cell apparatus to investigate the influence of the aforementioned factors and their interactions on the strength and deformation behaviour of CPB. The pressure cell has the ability to simulate curing conditions close to underground mine stope conditions at the laboratory scale with the application of controlled vertical pressure and drainage conditions. Furthermore, the rate of loading (or filling rate) as well as the filling sequences can be controlled in the apparatus, and relatively large size samples can be cured for laboratory testing purposes. This paper describes the developed experimental setup and presents the results of the investigation of the influence on the filling factors (filling rate and sequence), drainage conditions and curing stress and their interactions on the evolution of the strength and deformation behaviour of CPB at the early ages.

2. Experimental program

2.1. Materials and mix design

The materials used for the CPB preparation include binder, tailings, and water. The most popular type of cement used in backfill operations is ordinary Portland cement Type I (PCI), which is also used in this study. Tap water was used as the mixing water. Commercially available artificial silica tailings were used to prepare the fresh CPB. These tailings are made from ground silica, which contains 99.8% silicon dioxide (SiO_2). The grain size of the silica tailings is physically very similar to the natural tailings available in the mining sites of eastern Canada [30]. Natural tailings can contain several reactive chemical elements and often, sulphide minerals, which can interact with cement hydration and thus bring uncertainties to the interpretation of testing results. The use of silica tailings will minimize the uncertainties induced by these interactions.

Silica tailings, cement and water were mixed and homogenized in a food mixer for about 7 min. In all of the mixes, the cement proportion and water to cement ratio (w/c means mass of water/mass of cement) were kept constant at 4.5% and 7.6, respectively. The prepared fresh CPB mixtures were then poured into the developed pressure cell apparatus, which is described below.

2.2. Developed pressure cell apparatus

The main part of the developed apparatus is presented in Fig. 2. It includes a transparent perspex (acrylic plastic) cylinder with the diameter of 101.6 mm and height of 304.8 mm. Therefore, CPB specimens can be readily observed during the curing process through the transparent cylinder. Two plates cover the top and bottom of the cylinder. These plates are secured with three supporting steel rods. Only 200 mm of the height of the cylinder was filled with fresh CPB to keep the length-to-diameter ratio (H/D = Length/Diameter) of the sample in the order of two. A piston is mounted on the upper portion of the cylinder to (gradually) apply the required pressure. A maximum pressure of 600 kPa can be applied as the cell pressure, which gives the ability to simulate mine backfill up to a height of approximately 35 m, depending on the density of the backfill material. The top plate is connected to a compressed air storage tank through an air valve to exert pressure onto the piston. A pressure regulator and a pressure gauge were used to control the rate of pressure application. The loading system was calibrated so that the vertical load application corresponds to the controlled filling rate during the simulated stope filling. It was also assumed that arching does not occur. This means that the ratio of the stope height (H) to the width (W) is small enough ($H/W < 1$) so that the arching effect becomes negligible [31–33]. Thereby, the total self-weight stress governs the system.

To minimize the friction effect between the CPB and the cylinder wall, the inside of the cylinder body was pre-lubricated for optimum performance. The bottom plate was equipped with a

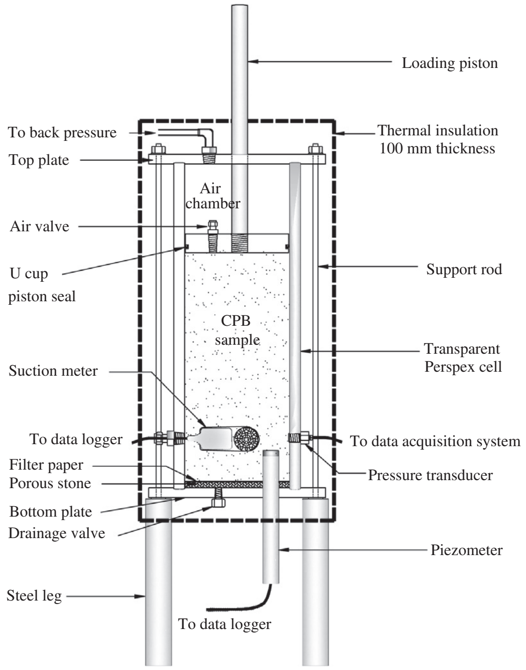

Fig. 2. Schematic diagram of the developed pressure cell apparatus.

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