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Effect of tailings fineness on the pore structure development of cemented paste backfill

Xing Ke, Xian Zhou, Xiaoshu Wang, Teng Wang, Haobo Hou *, Min Zhou *

Hubei Key Lab of Biomass Resource and Environmental Biotechnology, School of Resource and Environment Sciences, Wuhan University, Wuhan, PR China

HIGHLIGHTS

- Generally, the total porosity increases with the increase in tailings fineness.
- The tailings fineness significantly affects the pore-size distribution.
- The filling effect reduces the critical pore diameter.

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ABSTRACT

Cemented paste backfill (CPB) is an important engineering material nowadays. However, there is limited information about the influence of particle-size distribution on the pore structure properties of coarse tailings used in CPBs. This study investigates the effects of particle-size distribution on the pore-structure development of CPB samples. Therefore, this paper presents experimental results to assess the influence of the fineness of tailings on important parameters (total porosity, pore-size distribution, and critical pore diameter) cured for 7, 14, and 28 days. Mercury intrusion porosimetry tests are performed to provide insights into the pore structure of CPBs. Within the limits of this study, the total porosity and small pores (<10 μm) increased, whereas the critical pore diameter and large pores (>10 μm) decreased with the increase of tailings fineness. Furthermore, the influence of tailings fineness on the critical pore diameter decreased with extended curing time. Results show that the tailings fineness notably affected the pore structural properties of hardened CPBs.

1. Introduction

The cemented paste backfill (CPB), an important engineering material widely used globally in underground mines, is a mixture of dewatered tailings from the processing operations of mine, water, and hydraulic binders [1–9]. More than 8000 mining plants are found in China. Fine tailings are generally stored in a surface impoundment. However, this disposal method presents immense potential risks. In September 2008, 277 people died in an accident caused by iron ore tailings from a dam break in Shanxi Province, China [10]. Only three CPB systems are currently running in China. Unlike in Canada, Australia, Turkey, and other developed countries [11–14], CPB is a relatively new technology in China.

Unconfined compressive strength (UCS) is one of the most important properties of CPB [15–17]. The pore structure is widely accepted to significantly influence UCS, as well as other properties of CPBs [18]. Generally, mercury intrusion porosimetry (MIP) and nitrogen sorption/desorption (NSD) are the common methods employed to determine the microstructure of cement-based materials. MIP is typically used to measure the total porosity and pore-size distribution of porous materials. A wide range of pore-size distributions, varying from 0.001 to 1000 μm, can be determined by MIP, whereas NSD is only valid when the pore size of the samples is smaller than 60 nm [19]. Numerous researchers have studied the microstructure properties of cement-based materials by MIP [20,21].

Fall et al. [22] found that increasing curing time leads to finer microstructure and lower hydraulic conductivity. According to Fall et al. [23], macroporosity (0.05–1 μm) decreases with tailings fineness was reduced (25–75 wt.%). Yilmaz et al. [24] studied the effects of curing pressure and time, as well as binder type and content on the total porosity, mesoporosity (0.002–0.05 μm), macroporosity (>0.05 μm), and critical pore size of hardened CPB. Atahan et al. [25] studied the effects of water–cement ratio (w/c ratio) and curing time on critical pore diameter (dcr); they found that dcr is independent of the w/c ratio. Ercikdi et al. [26] found that the

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* Corresponding authors.
E-mail addresses: hhb6319@sina.com (H. Hou), zhoumin@whu.edu.cn (M. Zhou).

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CPB of desilimed tailings indicated smaller void ratio and lower porosity than those of the received tailings. Similar results were reported in previous studies [23,27]. Yu and Ye [19] found that the dcr of cement paste generally decreases with increasing curing time. Higher curing temperature leads to lower porosity and smaller critical pore size [28,29]. Sabine [30] and Zhang et al. [31] also studied the effects of temperature on microstructure. Li et al. [32] found that the samples incorporating 70% ground-granulated blast-furnace slag (GGBS) manifested higher specific surface area and larger total porosity than those of the reference sample. The effects of the drying method (oven-, vacuum-, and freeze-drying methods) and the water content on the pore structure of cement-based materials were also studied [33,34]. Yilmaz et al. [35] studied the effect of curing pressure on the strength development of the coarse tailings used in CPB; their results showed that the microstructure properties of cemented-based materials are significantly affected by the w/c ratio, binder content and type, water quality, tailing-particle gradation, mixing proportions, and curing time. In China, as well as India, fine tailings are separated from coarse tailings. The fine tailings are then stored in a surface structure, whereas the coarse parts are pumped into underground voids [36,37]. To the authors' knowledge, the effect of tailings fineness (<20 μm) on the microstructure properties of CPB is relatively limited, particularly in CPBs made of coarse tailings. Although Yilmaz et al. [35] investigated the impact of tailing-particle gradation on the microstructure development of CPBs made of coarse tailings, the pore-structure development of coarse tailings used in CPB deserves further attention.

The current study investigated the effect of tailings fineness and curing age on the pore-structure development of CPBs (coarse tailings used). The pore structure of each CPB is examined by MIP in terms of pore-size distribution, total porosity, and dcr to study how the pore structure is influenced by the tailings fineness and the curing age.

2. Materials and methods

2.1. Materials

The chemical and physical properties of the binder and tailings used are provided by Ke et al. [38]. The tailings fineness of the six samples is presented in Table 1.

2.2. Sample preparation

Detailed procedures of the sample preparation and curing conditions are completely provided by Ke et al. [38]. The samples were prepared at the curing ages of 7, 14, and 28 days before they were subjected to MIP tests. The central parts of the samples were sown into small particles with dimensions of around 3 mm and then immersed in liquid nitrogen for 5 min to cease hydration. The obtained particles were dried to a constant weight in a freeze dryer, as recommended by Yu and Ye [19]. Afterward, the pore structures of the prepared particles were assessed by MIP.

2.3. Pore-structure determination

In this study, pore-structure measurements were performed with a 241 MPa MIP, which determined the measurable pore-size range from 6 nm to 360 μm. The relationship between the pore diameter d_p (μm) and the pressure p (MPa) can be described by the well-known Washburn equation [39] based on a model of cylindrical pores:

$$d_p = -\frac{4\gamma \times \cos\theta}{p} \tag{1}$$

where θ is the contact angle between mercury and the pore wall, and γ is the surface tension of mercury. In this study, the surface tension of mercury was 0.480 N/m, and the contact angle was 140°. The relationship between the pore size and the applied pressure can be derived from Eq. (1).

3. Results and discussion

3.1. Total porosity

The MIP results of the influence of tailings fineness on the total porosity and pore-size distribution at 7- and 28-day curing times are presented in Fig. 1. Fig. 1 shows that the tailings fineness markedly affected the hydration kinetics, tailings-binder interaction, and pore-size development of CPBs as curing time increased. Total porosity generally rises with increasing tailings fineness in CPBs. Finer tailings indicate higher total porosity. This result is in good agreement with a previous report [27], which showed that the void ratio and total porosity increased significantly when the tailings fineness increased from 25 to 75 wt.%. Ercikdi et al. [26] also found that CPB specimens were made of desilimed tailings that generated low total porosity.

However, the UCS of CPB increases with the increased proportion of finer tailings [38]. Higher porosity generally results in lower compressive strength of CPB. This trend may occur because increases in the tailings fineness improve the gradation of tailings particles. According to Kesimal et al. [40], a proportion of 25 wt.% finer tailings can obtain the highest compressive strength, whereas 40–45 wt.% fineness is the optimal content for the compressive strength gain, as reported by Fall et al. [23]. Notably, tailings fineness, tailings-binder interaction, and curing age significantly affect the pore-structure development and strength-gain characteristics of CPB, considering the obtained results from the current and previous studies of the authors [38].

3.2. Porosity proportion

As proposed by several researchers [41,42], the area under the pore-size distribution curve can be used to analyze pore structure development. According to the International Union of Pure and Applied Chemistry (IUPAC), micropores are smaller than 2 nm, mesopores range between 2 and 50 nm, and macropores are >50 nm [43]. Oltulu and Sahin [44] divided the pore-size distribution into six portions in terms of pore diameter. Ouellet et al. [45] separated pore-size distribution into two portions (<0.3 μm and >0.3 μm). Fall and Samb [28] divided pore-size distribution into two portions (<1 μm and >1 μm) to investigate the effects of thermal loads on pore structure. Abdul-Hussain and Fall [46] divided the pore-size distribution into three portions (<1 μm, 1–10 μm, and >10 μm); they found that increases in binder content are associated with a higher proportion of pores (<1 μm) and lower proportion of pores

Table 1
Tailings fineness of six CPB samples.

	M-1	M-2	M-3	M-4	M-5	M-6
Tailings fineness (wt.%)	4.18	8.86	13.53	18.21	22.88	27.55