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Macroscopic and microscopic fracture features of concrete used in coal mine under chlorine salt erosion

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ABSTRACT

The microscopic morphology and pore structure characteristics of concrete with composite admixtures (fly ash and mineral powder) after chlorine salt erosion were analyzed via scanning electron microscopy (SEM) and mercury injection porosimetry (MIP), providing the basis for the design and maintenance of concrete shafts in coal mines. The above-mentioned characteristics were compared with the macroscopic characteristic of concrete fractures under uniaxial compression. The results show that the macroscopic fracture characteristics of concrete under uniaxial compression change from longitudinal split fracture and oblique section shear fracture to conjugate cant fracture, and the degree of breakage increases. Interface cracks, cement paste cracks, spherical surface cracks, and aggregate cracks appear in concrete under uniaxial compression. In the early stages of corrosion, the original cracks which are obvious are repaired. When the corrosion becomes more serious, cement paste cracks appear, and the number of harmful holes increases while the number of harmless holes decreases. This study also reveals the relationship between the macroscopic properties and microscopic structure of concrete under chloride salt erosion. Finally, the paper preliminarily discussed the relationship between the macroscopic properties and mesoscopic characteristics of concrete under chlorine salt erosion.

1. Introduction

Erosion mediums in groundwater can cause corrosion damage to concrete shafts in coal mines, potentially leading to safety problems that cannot be ignored [1–4]. Therefore, the durability of the concrete used in shaft linings has attracted considerable research attention. High-strength and high-performance concrete is gradually applied to shaft lining constructions. Corrosive salts in groundwater mainly include sulfuric acid root ions, chloride ions, and bicarbonate ions which cause damage to the concrete in shaft linings. Chemical reactions induced by the sulfate ions produce large volumes of salt compounds, leading to local stress increase and the deterioration of concrete. Therefore, this issue is being investigated by several researchers. On the other hand, many studies have focused only on the corrosive effects of chloride ions on steel while ignoring similar negative effects on concrete. Yang found that chloride ions can also degrade the performance of concrete [5]. The present paper studies the effects of chloride ions on the performance of concrete at the macroscopic and microscopic levels.

The microscopic structure of concrete determines its macroscopic properties, whereas changes in the macroscopic properties of concrete affect its microscopic structure [6]. The microscopic structure of concrete has attracted considerable research attention. The link between the macroscopic performance and microscopic structure of concrete has emerged as a topic of particular interest [7].

R. Brady Williamson, Karen Scrivene, Jennings and Midgley investigated the microscopic morphology and structure of concrete. Wart, Kim, Dwight and Viehland carried out extensive studies on the chemical composition of concrete (calcium silicate hydrates, C–S–H gel, etc.). Zhang et al. meticulously examined the morphology and structure of hydration products, including grain size and interfacial transition zone (ITZ) interface, by using modern analysis techniques such as scanning electron microscopy (SEM) and X-ray power diffraction (XRD) [8–10]. Xiao et al. studied the pore structure of concrete using mercury injection porosimetry (MIP) [11–13]. Further, Yang et al. studied the relationship between the average pore size and macroscopic parameters (e.g., osmotic pressure and chloride ion permeability coefficient) of concrete [14,15].

Many other studies have investigated the microscopic structure of concrete. However, thus far, the link between the microscopic structure and macroscopic properties of concrete has not been

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Table 1
Mix proportion of concrete.

Water-cement ratio (%)	Admixture	Content (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	Mineral powder (kg/m^3)	Sand (kg/m^3)	Stone (kg/m^3)	Water (kg/m^3)
32	F+G	15+35	226	68	158	740	1112	145

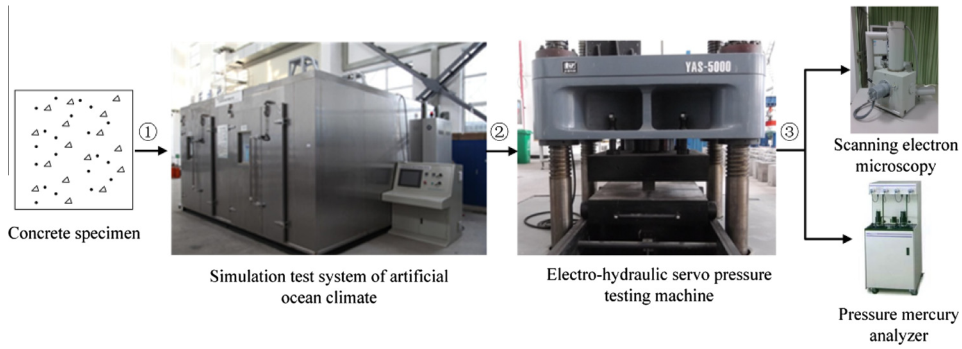

Fig. 1. Test flowchart and equipment.

studied extensively. In the present study, the microscopic and pore structure characteristics of concrete with mineral admixtures (fly ash and mineral powder) are analyzed via SEM and MIP. In addition, the macroscopic fracture and microscopic structure of concrete under uniaxial compression are investigated. Thus, the relationship between the macroscopic properties and microscopic structure of concrete is revealed.

2. Experimental

2.1. Materials and mix proportion

The 42.5 ordinary Portland cement used in the experiment was provided by Xuzhou Zhonglian. Grade 1 fly ash was provided by Xuzhou Maochun, and mineral powder was provided by Xuzhou Zhuben. The fineness modulus of river sand was 2.8 with apparent density 2679 kg/m^3 and 2.49% silt content. The particle size of stone was 5–20 mm with apparent density 2719 kg/m^3 and 0.54% silt content. The slushing agent for concrete was carboxylic acid provided by Wulong.

The mix proportion of concrete is summarized in Table 1. Fly ash and mineral powder are denoted by F and G, respectively. The forms of the concrete samples were split after 24 h, and the bottom surface of every sample was cleaned using a wire brush. Then, the samples were preserved for 28 days in standard conditions.

2.2. Test method

The size of a concrete sample was 100 mm × 100 mm × 100 mm. Each group included three samples. The test flowchart and equipment are shown in Fig. 1. The test process is described as follows.

First, concrete samples preserved for 28 days in standard conditions were placed in a simulation system with an artificial marine environment for salt spray erosion. The relative humidity was 75%–80% and the mass concentration of NaCl solution was 5%. The salt spray time was 12 h and the drying time was 12 h per day. Second, the concrete samples were subjected to a uniaxial compression experiment after erosion for 30, 110, 190, and 270 days. Then, the concrete chippings were stored in alcohol solution to prevent hydration. Finally, the concrete chippings were subjected to SEM and pressure mercury experiments.

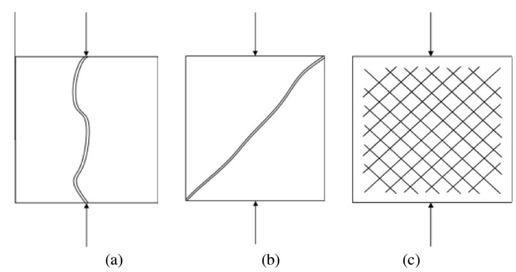

Fig. 2. Failure characteristics of concrete under uniaxial compression.

3. Results and discussion

3.1. Macroscopic fracture characteristics of concrete under uniaxial compression

The fracture characteristics of concrete under uniaxial compression are generally assumed to be of three main types: longitudinal splitting fracture (Fig. 2a), single bevel shear fracture (Fig. 2b), and conjugate cant shear fracture (Fig. 2c) [16].

Fracture characteristics of concrete that were depicted under uniaxial compression when corrosion time $t = 30$, 110, 190, and 270 days are shown in Fig. 3. The fracture characteristics of concrete undergo obvious changes as the corrosion time increases. In addition, the breakage degree increases with the corrosion time. The specific analysis is described as follows.

The fracture concrete samples exhibit longitudinal splitting fracture and single bevel shear fracture when the corrosion time t is 0–190 days, and the breakage degree is more severe. In fact, when the corrosion time t is 0–190 days, the negative effects of chloride ion erosion are not obvious, while the microscopic structure and macroscopic mechanical properties are improved by hydration products and chlorinated compounds. Thus, the breakage degree of concrete is moderate. The edges of the concrete samples show greater breakage due to the fact that chloride ion erosion affects the first parts.

The fracture concrete samples exhibit conjugate cant shear fracture when the corrosion time t is more than 190 days, and the number of surrounding broken stones is greater than that when t is 0–190 days. In fact, the number of microscopic cracks and pores, due to chlorine salt erosion of the concrete samples, increases