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Experimental Study on Chloride Ion Penetration Resistance of Coal Gangue Concrete under Multi-Factor Comprehensive Action

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Abstract

In order to investigate the chloride ion penetration resistance of coal gangue concrete under multi-factor comprehensive action, the non-steady-state accelerated chloride ion migration test was used to test the chloride diffusion law of coal gangue concrete specimens by crack width, curing temperature and water-cement ratio. Three groups of crack width (0 mm, 0.05 - 0.12 mm, 0.12 - 0.2 mm), three curing temperatures (high temperature 45, medium temperature 25, low temperature 10), three water cement ratios (0.3, 0.4, 0.5) were set in the experiment. The results show that when the curing temperature and water cement ratio are constant, the crack width less than 0.12 mm has little effect on the chloride content and chloride diffusion coefficient. When the crack width is larger than 0.12 mm, the chloride penetration depth increases with the crack width. The resistance to chloride ion penetration of gangue concrete is greatly influenced by the water cement ratio. The influence degree of three factors on chloride ion migration coefficient of gangue concrete is as follows: water cement ratio > crack width > curing temperature.

Keywords

Coal Gangue Concrete, Chloride Ion Penetration,
Water Cement Ratio, Crack Width, Curing Temperature

1. Introduction

With the acceleration of China's modernization process, coal gangue is accompanied by coal mining and the use of coal resources. However, the comprehensive utilization rate of coal gangue is relatively low, and it brings adverse conse-

quences such as occupying land and polluting water sources of air pollution [1]. How to make use of coal gangue to turn waste into treasure and harm into benefit has become a new economic growth point [2] [3].

Coal gangue can be used as aggregate to prepare concrete after crushing and screening, which can reduce the mining and utilization of ore, and has remarkable economic benefits. The main obstacle to the application of gangue concrete structure is that its durability research is insufficient compared with ordinary concrete, such as chloride ion penetration resistance. Some studies have used coal gangue as fine aggregate, but it is obviously simpler and more economical to use coal gangue as coarse aggregate. At present, research has mainly discussed the influence of gangue and admixture content on chloride ion penetration resistance of concrete [4] [5]. There are cracks in concrete structures in practical projects, and the curing temperature of concrete in different areas is also significantly different. In view of the above situation, the comprehensive effect of various environmental factors was studied. The effect of different crack width, curing temperature and water-cement ratio on chloride ion permeability [6]-[12] of gangue concrete was studied by using the unsteady accelerated chloride ion migration test [13].

2. Test Materials and Methods

2.1. Test Materials

The P O 42.5 grade cement produced by Hebei Yanxin Material Co., Ltd. is selected with a specific surface area of 362 m^2/kg, initial setting time of about 75 minutes and final setting time of about 330 minutes. Coal gangue is selected from Shuozhou Coal Mine, Shanxi Province. After crushing by jaw crusher, it is screened and calcined in muffle furnace at 700˚C for 2 hours. Fine aggregate is selected to calcine coal gangue sand with good gradation. Coarse aggregate is selected to calcine coal gangue at 700˚C with continuous gradation of 5 - 20 mm in diameter. The main chemical composition of coal gangue is shown in **Table 1**. **Figure 1** shows the XRD spectra of raw and calcined coal gangue at 700˚C. The main chemical composition of raw coal gangue is kaolinite and muscovite. After calcined at 700˚C, the diffraction peak of kaolinite decreases and the diffraction peak of quartz increases.

2.2. Test Methods

According to JGJ/T 193-2009 "Standard for Testing and Evaluating Durability of Concrete" and GB/T 50082-2009 "Standard for Testing Method of Long-term Performance and Durability of Ordinary Concrete", 500 mm × 500 mm × 50 mm cubic standard specimens were made. Fissure specimens with different width were fabricated by insertion method. After casting, the mould was sealed and covered with film and cured for 24 hours at different curing temperatures. Cylindrical specimens with thickness of 50 mm and diameter of 100 mm were drilled by HZ-20 concrete core drilling machine (MZ175). The specimens were

Table 1. Main chemical composition of coal gangue %.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
58.46	28.01	2.56	0.74	0.62	0.16	1.21

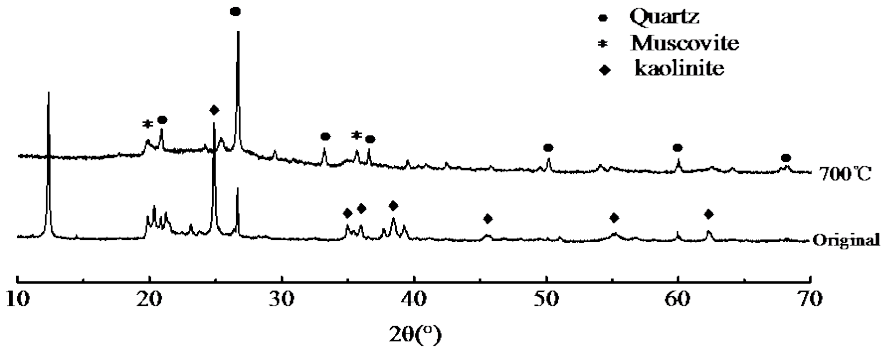

Figure 1. XRD profile of raw and 700 degree calcined coal gangue.

moved to the standard curing room and maintained to the testing age. The chloride ion was introduced into gangue concrete through the experiment of accelerating chloride ion migration in unsteady state. In addition to quantitative analysis, electron microscopy observation (SEM) was also used for micro-assisted analysis (**Table 2**, **Table 3**).

3. Test Results Analysis and Chloride Ion Penetration Resistance Analysis

Test Results Analysis

Figure 2 shows the effect of curing temperature and crack width on penetration depth of chloride ion when water cement ratio is 0.5. It can be seen from the graph that when the curing temperature is constant, the chloride ion content of three kinds of gangue concrete with different crack widths decreases with the increase of penetration depth, and the specimen without cracks is more obvious. When the curing temperature is relatively large, it can be seen that the slope of chloride ion content is larger, which shows that the change of temperature has a significant effect on the chloride ion content of coal gangue concrete with the change of depth. The side reflects that the hydration degree of cement is more complete at higher temperature. The denser the structure of gangue concrete is, the smaller the electric flux is with the increase of depth, that is, the chloride ion content decreases more obviously.

From **Figures 2(a)-(c)**, it can be seen that when the water cement ratio is fixed, the influence degree of electric flux of gangue concrete is crack width > curing temperature.

Figure 3 shows the variation of chloride ion transfer coefficient at 25˚C. It is found that the chloride ion migration coefficient of gangue concrete increases with the increase of water cement ratio, that is, the chloride ion penetration

Table 2. Mix proportion of gangue concrete.

No.	Water cement ratio	Mix proportion			
		Water	Cement	Fine aggregate	Coarse aggregate
1	0.3	185	616	570	929
2	0.4	185	463	628	1024
3	0.5	185	370	663	1082

Table 3. Test design group.

Specimen design	Water cement ratio	Crack width	Curing temperature
1	0.3, 0.4, 0.5	0 mm	10
2			25
3			45
4		0.05 - 0.12 mm	10
5			25
6			45
7		0.12 - 0.2 mm	10
8			25
9			45

resistance of gangue concrete decreases. This is because the larger the water cement ratio means that the amount of cement per unit volume decreases, resulting in the reduction of hydration products and the increase of capillary pipelines at the interface between cement paste and aggregate, thus speeding up the chloride ion transport rate in concrete. Therefore, the chloride ion penetration resistance of gangue concrete is greatly affected by water cement ratio.

Obviously, the chloride ion migration coefficient increases with the increase of crack width, but the difference is not significant when the crack width is less than 0.12 mm. When the crack width is more than 0.12 mm, the chloride ion content and migration coefficient increase significantly with the increase of crack width. It can also be seen from the comparative analysis that when the curing temperature is constant, the chloride ion transfer coefficient of coal gangue concrete has the following influence degree: water cement ratio > crack width.

4. Analysis of Chloride Ion Penetration Resistance of Gangue Concrete

The transport process of chloride ion in gangue concrete is mainly affected by porosity and internal transport channels. The higher the porosity, the more the transport channels, the worse the chloride ion penetration resistance of concrete. The internal structure of gangue concrete was observed by scanning electron

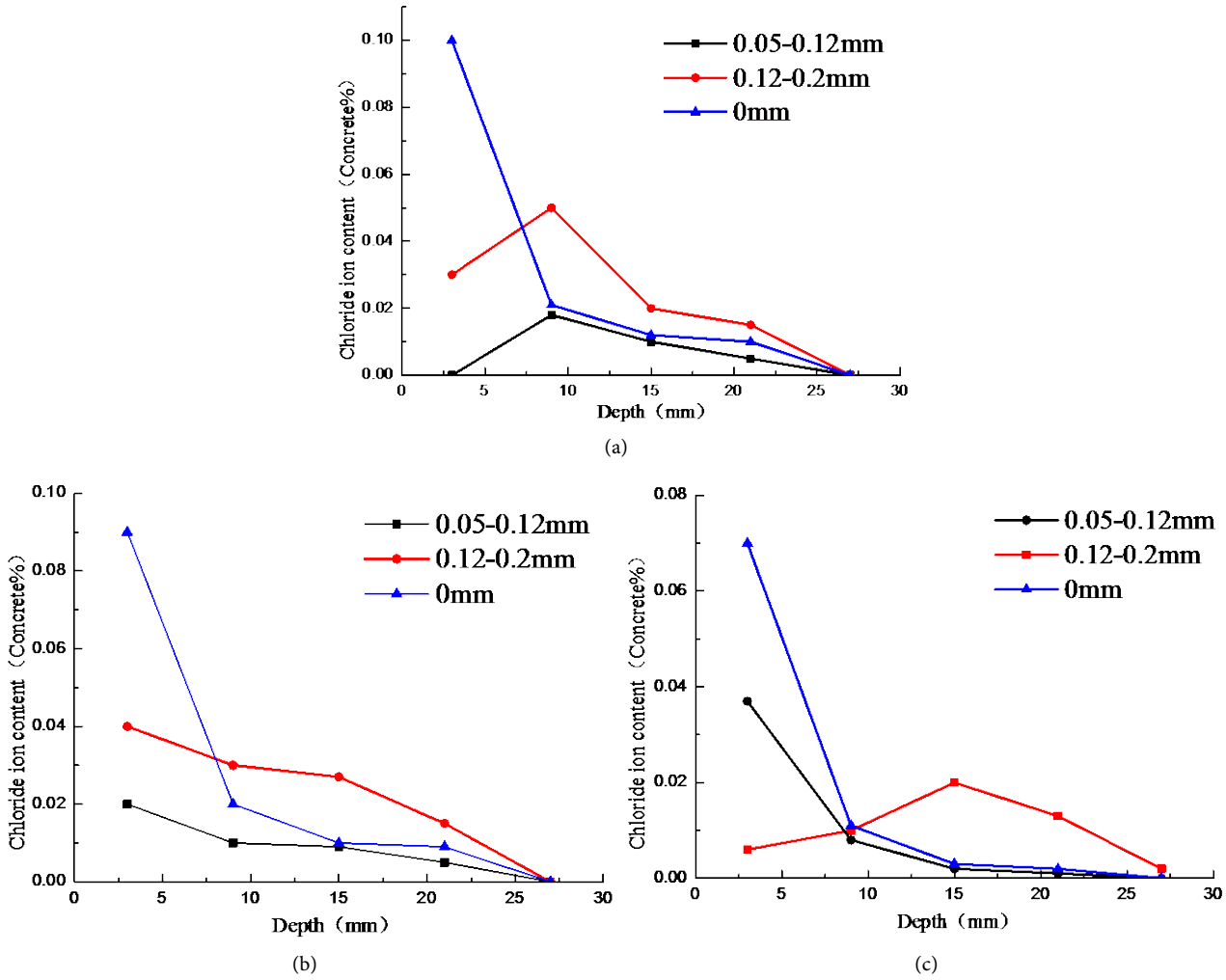

Figure 2. Variation of penetration depth of gangue concrete. (a) Water cement ratio: 0.5 curing temperature: 45˚C; (b) Water cement ratio: 0.5 curing temperature: 25˚C; (c) Water cement ratio: 0.5 curing temperature: 10˚C.

microscopy (SEM). As shown in **Figure 4**, the structure of gangue concrete is relatively dense, and a large number of needle-like crystals fill the voids, which reduces the chloride ion in the gangue concrete in-depth channels. From the point of view of hydration reaction, coal gangue will absorb water when it is mixed with concrete, which will reduce the water-cement ratio and help to resist chloride ion penetration in coal gangue concrete. Because of the large specific surface area of coal gangue, it is easy to adhere to cement hydration products. The active Al_2O_3, SiO_2 on the surface of coal gangue react with $Ca(OH)_2$ in cement slurry, and the C-S-H gel and $Ca(OH)_2$ are carefully adhered together to make the overall structure of the system more dense and resistant to chloride ion permeability.

5. Conclusions

1) The chloride ion penetration resistance of gangue concrete is greatly affected by water cement ratio. The influence of three factors on chloride ion

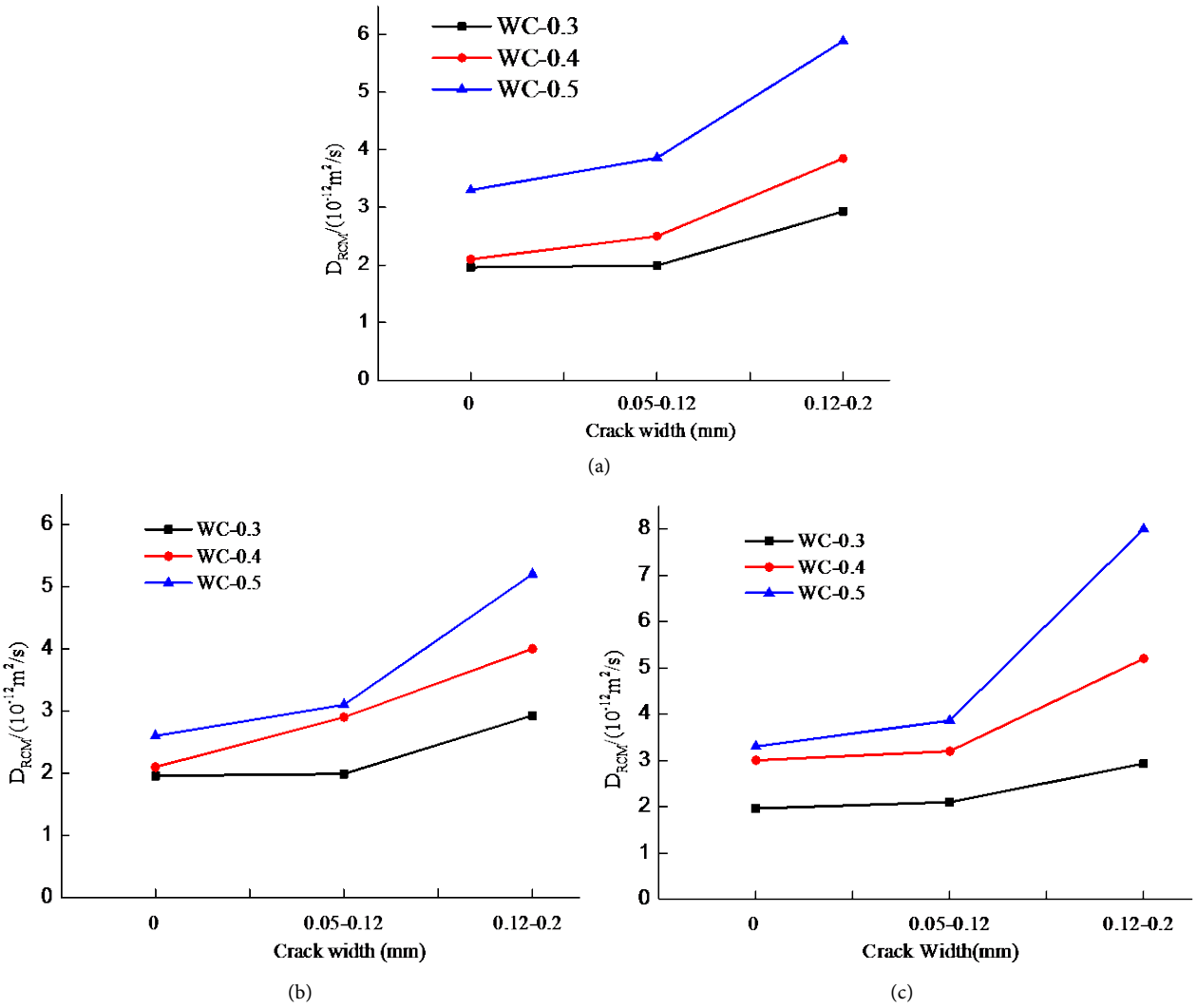

Figure 3. Variation law of chloride ion transport coefficient in gangue concrete.

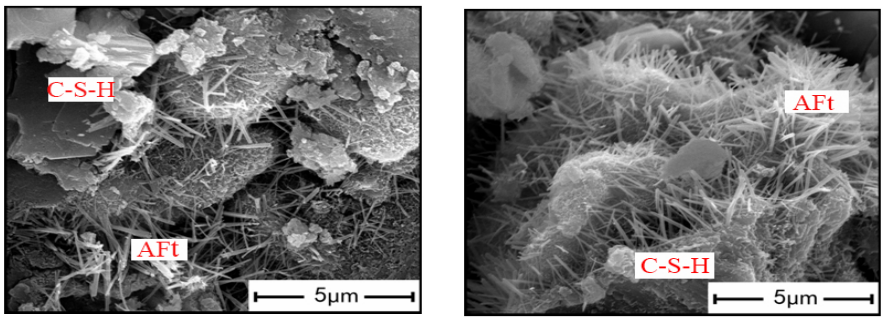

Figure 4. SEM morphology of gangue concrete.

transfer coefficient of gangue concrete is as follows: water cement ratio > crack width > curing temperature.

2) When the crack width is less than 0.12 mm, the difference is not significant. When the crack width is greater than 0.12 mm, the chloride ion content and migration coefficient increase significantly with the increase of the crack width.

3) It can be seen from the scanning electron microscope that the moisture absorption of coal gangue reduces the actual water cement ratio of concrete and the internal porosity of concrete. The close distribution of C-S-H gel and $Ca(OH)_2$ produced by the two hydration increased the density of the whole structure and enhanced the resistance to chloride ion penetration.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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