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Coupled effect of axially distributed load and carbonization on permeability of concrete

Jiaying Sun [a,*], Liguo Lu [b]

[a] Ningbo Institute of Technology, Zhejiang University, Ningbo 315100, China
[b] Department of Civil Engineering, Shanghai University, Shanghai 200072, China

HIGHLIGHTS

- Load and carbonization effects cause changes in permeability of concrete defects.
- Defects were smaller in carbonized than uncarbonized concrete at 20% ultimate load.
- Cl^-, water, and gas permeabilities improved under load and carbonization effects.
- Concrete showed more defects and decreased anti-permeability at 60% ultimate load.
- Concrete showed many more defects under 60% ultimate load and carbonization.

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ABSTRACT

Rebar corrosion strongly influences concrete durability. Furthermore, carbonization and chloride permeability caused by passivation of steel bars are the main causes of reinforcement corrosion. Concrete structures are commonly subjected to compressive stress. We discuss the coupled effects of axial compression load and carbonization on chloride, gas, and water permeabilities. We observed that gas and water permeability coefficients of concrete decrease with prolonged carbonization under same load with varying degrees of decline. However, coupled effect of axial compression load and carbonization on chloride penetration is more complex, as hydration products of cement and carbonized product produce a binding effect on chloride.

1. Introduction

Carbonization and chloride permeability are the two main causes of reinforcement corrosion in reinforced concrete [1–3]. Under normal circumstances, carbon dioxide and chlorides, upon reaching the surface of a steel bar, reduce the alkalinity inside concrete and cause the failure of the passivation film on the surface of the steel bar, ultimately causing the corrosion of the steel bar [4–5]. In particular, we found that in coastal areas, steel bars were greatly corroded even under low chlorine ion concentration and small carbonization depth [6] owing to the coupled effect of axial compression load. In this light, the ratio of chloride and hydroxide concentrations is an important parameter determining reinforcement corrosion [7]. Many studies have focused on concrete performance in terms of the coupled effect of carbonization and chloride penetration under axial compression loads [8–9], when the load is small, chloride permeability decreases slowly with an increase in load, but when the load exceeds the critical load, the chloride permeability increases significantly [10–11]. In this study, we used custom-made loading equipment to load concrete specimens; conduct a rapid carbonization test; analyze the microstructure evolution; measure the coupled effect of axial compression load and carbonization on chloride, gas, and water permeabilities and anti-chloride-ion, anti-gas, and anti-water permeabilities; and apply the rapid chloride migration coefficient (RCM) method to determine the chloride diffusion coefficient.

2. Materials and methods

2.1. Experimental materials

In the tests conducted in this study, P.O 42.5 cement (Zhejiang Leomax Group Special Cement Co., Ltd.), natural river medium sand (fineness modulus: 2.58), continuous grading gravel (size: 5–16 mm), and ordinary tap water were used. Table 1

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[*] Corresponding author at: Ningbo Institute of Technology, Zhejiang University, 1, Xuefu Road, Ningbo 315100, Zhejiang Province, China. Tel.: +86 133 1162 0603.
E-mail addresses: jakys@163.com (J. Sun), luliguo0115@163.com (L. Lu).

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Table 1
Mix proportion of concrete.

Cement (kg m^{-3})	Water (kg m^{-3})	Stone (kg m^{-3})	Sand (kg m^{-3})
284	152	1244	730

shows the mix of this concrete, which is the most widely used type of C30 concrete. Tables 2 and 3 list the chemical composition and the physical and mechanical properties of cement, respectively. It was determined that the 28 days cube compressive strength of concrete is 33.7 MPa.

2.2. Specimen production and test methods

A cylindrical concrete specimen (100 mm × 50 mm) was used, and the cylindrical test mold (100 mm × 50 mm) was specifically tailored to avoid the effects of cutting on concrete. Form stripping was performed after maintenance for 24 h, and standard curing was performed for 28 d.

In the concrete gas permeability test, a cylindrical concrete block (diameter: 150 mm, height: 50 mm) was adopted according to the RILEM TC 116-PCD test method. After curing for 28 d, it was dried in a dry oven for 7 d at 105 ± 5 °C, removed, and immediately sealed. The penetration of nitrogen gas at seepage pressures of 1.5, 2.0, and 3.0 bar (absolute pressure) was tested. Ki was calculated under each pressure, and its average value was considered the permeability coefficient K of each concrete mix.

The anti-water penetration capability was tested in accordance with the GB/T 50082-2009 "standard for test methods of long-term performance and durability of ordinary concrete." The chloride penetration was determined used the RCM method according to the GB/T 50082-2009 "ordinary concrete long-term performance and durability test method standards."

The durability loading device used in this test conformed to the design principles for pre-tensioned, pre-stressed concrete (see Fig. 1) [12].

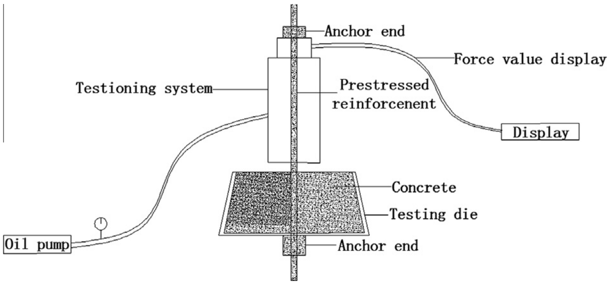

Fig. 1. Preloading device of concrete diagram.

3. Results and discussion

3.1. Coupled effect of axial compression load and carbonization on gas permeability

The gas permeability under axial compression load was tested. Compared with the no-load condition, the load caused changes in the internal microstructure of concrete. Under small load, native microdefects in concrete were repaired to a certain extent, and the anti-gas permeability of concrete increased. A further increase in load promoted the repopulation of closed microcracks and generated many new microcracks and other defects, as a result of which defects penetrated the channel of the eroded concrete ingredients and degraded the anti-gas permeability. On the other hand, calcium and carbide products produced via concrete carbonization, in which water and carbon dioxide react with calcium hydroxide to produce calcium carbonate, have a certain physical filling effect in concrete as well as a compaction effect that reduces the porosity of the hardened concrete paste; therefore, it can increase concrete's density and anti-gas permeability, leading to an overall improvement in concrete's pore characteristics.

Fig. 1 shows the coupled effect of axial compression load and carbonization on the gas permeability coefficient of concrete. Under the same load, the gas permeability coefficient reduces with prolonged concrete carbonization.

As shown in the figure, when the load is 60% of the limit load, the gas permeability coefficient of concrete exceeds 17×10^{-16} m^2, which is far greater than that of normal concrete. This is because the improved anti-gas permeability caused by carbonization cannot sufficiently compensate for the degraded concrete microstructure caused by the large load, resulting in the overall degradation of the anti-gas permeability coefficient.

Table 2
Chemical composition of cement (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO
20.58	5.86	4.85	59.53	2.01	3.75

Table 3
Cement performance parameters.

Water requirement of normal consistency (mL)	185	
Setting time (min)	Initial set	105
	Final set	165
Stability	Qualified	
Strength		
Age (d)	3	28
Fracture resistance (MPa)	4.5	6.4
Resist compression (MPa)	33.1	47.2

3.2. Coupled effect of axial compression load and carbonization on water permeability

Fig. 2 shows the coupled effect of axial compression load and carbonization on the water permeability. Under the same load, the water penetration depth decreases with prolonged carbonization. Carbonization reduces the water permeability via the physical filling effect of carbide products and the chemical compaction effect that reduces concrete's hardened paste porosity and improves its density.

When the axial compression load is 60% of the ultimate load, the water penetration depth is large and much greater than that in normal concrete. This is because although carbonization can improve the anti-water permeability of concrete, it cannot sufficiently compensate for the negative effects of the large number of microdefects produced by an excessive load that degrade anti-water permeability.

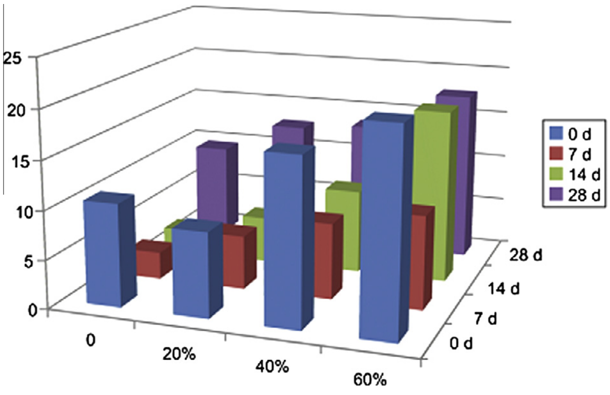

Fig. 2. Gas permeability coefficient of concrete under coupled effect of axial compression load and carbonization (10^{-16} m^2).