A Novel Method for Increasing the Concrete Resistance to Chloride Ions Erosion

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Abstract. Concrete structures generally play an important role in the infrastructure construction. The corrosion of reinforcing steels in concrete structures is one of the main causes of the degradation and reduction of their service life, especially when they are exposed to marine environment or de-icing salts. An understanding of the process of chloride transportation in concrete is of great importance for engineers to predict the service life of concrete structures. Therefore, we synthesized corrosion inhibitor for improving the chlorine resistance of concrete.

Keywords: Concrete; service life; corrosion inhibitor; chlorine resistance.

1. Introduction

The durability of concrete plays an important role in the normal use of infrastructures, such as roads and railways. Among these, erosion by chloride salts in saline soil and salt lake environments is the key factor that affects the durability of concrete structures [1,2,3]. However, the process of concrete erosion is very complex that has been studied over the past few years [4]. Cl− diffuses into the concrete through the following ways: (1) pores in the matrix, (2) interface transition zones (ITZ), (3) cracks in concrete. The Cl− existing in the interior of concrete mainly destroys the passive film on the surface of steel rebar causing steel corrosion [5,6,7].

Therefore, a large number of scholars have made a large number of Cl- erosion tests and studied the diffusion process of Cl− in concrete. According to Li Lin's study[8],the Cl− diffusion coefficient increased with the increase in stress degree and environment temperature through Cl− erosion concrete tests with various experimental conditions and the compressive strength of concrete declined after prolonged erosion. Audenaert et al.[9] have established the diffusion equation of Cl− in concrete by using Fick's second law and found that the diffusion rate of Cl− in concrete varied after different erosion times. Wang[10] has found that the essence of Cl− diffusion in concrete is the migration of charged particles in the pore solution, and the driving force of diffusion is mainly concentration differences between the inside and outside of the concrete as well as the pressure difference, humidity difference, and convection of pore liquid.

According to the previous studies and based on the diffusion character of Cl^- in concrete, we synthesized a novel corrosion inhibitor for improving the chlorine resistance of concrete.

2. Materials, specimen preparation and test method

2.1 Materials

The cement was used as Portland cement CEM-1 42.5, and its chemical and physical properties are shown in Table 1 and 2. The river sand with 2680 kg▪m^{-3} apparent density and 2.8 fineness modulus was used as fine aggregate. The crushed limestone prepared from 5~10 nm particles and 10~20 mm particles at a weight ratio of 4:6 was used as coarse aggregate. The other components were tap water and polycarboxylate superplasticizer was used as water reducing agents.

Table 1 Chemical compositions of cement (wt./%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O_{eq}	LOI	f-CaO	Cl^-
21.32	4.31	3.38	61.26	2.47	2.55	0.57	1.31	0.86	0.014

Table 2 Physical properties of cement

Density / $kg \cdot m^{-3}$	Specific surface / $kg \cdot m^{-3}$	Setting time / min		Flexural strength / MPa		Compressive strength / MPa	
		Initial	Final	3 d	28 d	3 d	28 d
3160	340	99	159	5.7	8.8	26.2	50.4

2.2 Preparation of corrosion inhibitors

Three barium salt barium nitrate, barium hydroxide, and barium carbonate are working as the main components of corrosion inhibitors. Three barium salts with a ratio of 3:5:2 were dissolving in an aqueous solution of 100 mL at 85 ℃. And then adding 200 g silica emulsion and stirring well, finally the sample was dryed in vacuum oven at 60 ℃

2.3 Preparation of specimen

The mix proportion of concrete specimen with different dosage of corrosion inhibitors were shown in Table 3.

Table 3 Concrete mix proportion (kg/m^3)

Specimen	Admixture	Cement	Coarse aggregate			Fine aggregate	Water	corrosion inhibitors
			＞ 20mm	**（10～20） mm**	**（5～10） mm**			
F-0	1.6	444	105.2	526.4	421.2	763	160	0
F-1	1.6	430.8	105.2	526.4	421.2	763	160	13.3
F-2	1.6	417.6	105.2	526.4	421.2	763	160	26.6
F-3	1.6	404.4	105.2	526.4	421.2	763	160	40.0
F-4	1.6	390.8	105.2	526.4	421.2	763	160	53.2

2.4 Curing method of concrete

After forming, the specimens were placed in a room with a temperature of (20 ± 3) ℃ and relative humidity > 50% for 24 h. After mold removal, the specimens were immediately placed in a standard curing room with a temperature of (20 ± 2) ℃ and relative humidity > 95% until the specified age.

2.5 Compressive strength

The standard curing age for testing the compressive strength pf concrete is 28 days. Experiment process was according to GB/T 50081-2019; The size of the test block is 100 mm×100 mm×100 mm, with 3 specimens in each group.

2.6 Chloride ion diffusion coefficient of concrete

The test was carried out according to Appendix B2 of CCES 01-2004. The size of the test block is φ100 mm×50 mm, with 3 pieces in each group.

3. Results and discussion

3.1 The effect of corrosion inhibitors on the workability of concrete

As shown in the Figure 1, it can be seen that with the increase of the corrosion inhibitors' dosage, the slump of concrete firstly increased and then decreased. With the dosage of corrosion inhibitors further increasing, the concrete slump have decreased a lot. As shown Figure 2, comparing with reference F-0, the slump of F-2, F-3, F-4 have decreasd -20%, 47%, 60% and 73%. This phenomenon can be attributed to the higher specific surface area of corrosion inhibitor, which inducing to a larger water amount for dispering the cement particle.

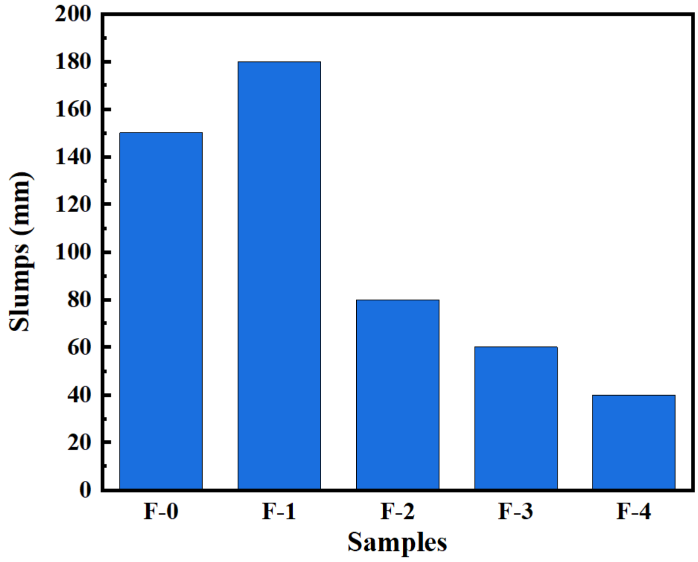

Figure1 The slump of concrete with different mix proportions

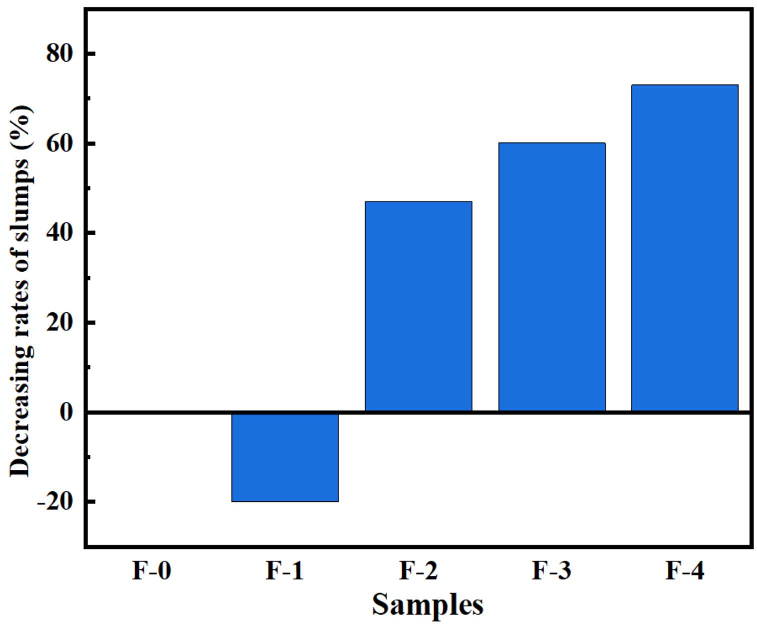

Figure 2 The slump decreasing rate of concrete in the presence of different dosgaes of corrosion inhibitors

3.2 The effect of corrosion inhibitors on the compressive strength of concrete

Moveover, the compressive strength of concrete was shown in Figure 3, it can be found that with the corrosion inhibitor increasing, the compressive strengths of concretes were also improved firstly and then decreased. However, the compressive strength of concrete containing corrosion inhibitor still showed higher compressive strength, which indicates that the introduced corrosion inhibitor promoted the hydtation of cement and made the concrete structure more dense.

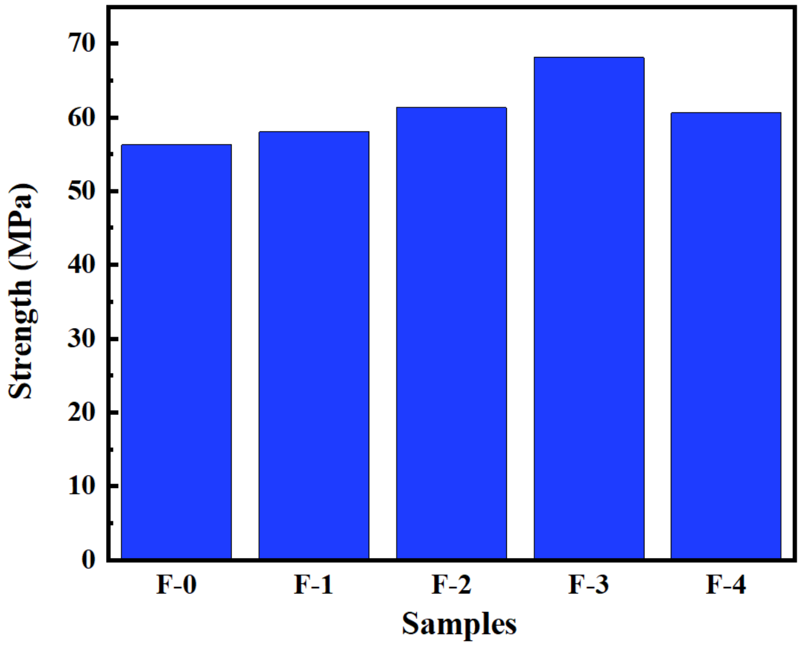

Figure 3 The compressive strength of concrete in the presence of different dosgaes of corrosion inhibitors

3.3 The effect of corrosion inhibitors on the chloride ion diffusion coefficient of concrete

Lastly, we also tested the chloride ion diffusion coefficient of concrete with different dosages of corrosion inhibitors. Test results were shown in Figure 4, with dosage of corrosion inhibitors increasing, the chloride ion diffusion coefficient of concrete has decreased obviously, comparing with reference F-0, the chloride ion diffusion coefficient of F-1, F-2, F-3, and F-4 have decreased 4.7%, 17.3%, 22.9%, 27.9%, respectively. The introduced corrosion inhibitor prevents the diffusion of chloride ion, it can be attributed to the chemical reaction of chloride ion and the corrosion inhibitor, which decreasing the diffusing rate of chloride ions in the concrete.

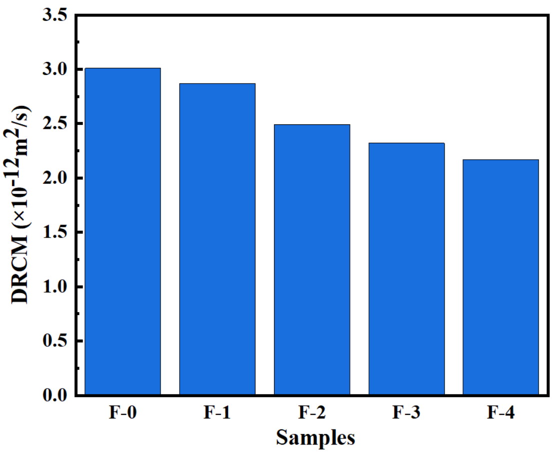

Figure 4 The chloride ion diffusion coefficient of concrete in the presence of different dosgaes of corrosion inhibitors

4. Conclusion

According to the test results, it can be concluded that (1) The corrosion inhibitor influenced the workability of concrete, with the corrosion inhibitor increasing, the slump of concrete will decrease gradually. When the dosage of corrosion inhibitor was over 3%, this phenomenon will be more obviously. (2) The compressive strength results showed that the introduced corrosion inhibitor would improve the compressive strength through densifying the microstructure of concrete. (3) The chloride ion diffusion coefficient of concrete exhibited that the introduction of corrosion inhibitor effectively decreased the diffusing rate of Cl^-, improving the Cl^- resistance property of concrete.

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