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Experimental Research for Influence Factors on Infusibility of Concrete Chloride Ion under Erosion Environment

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In view of the characteristics of erosion environment of underground concrete structure in Guangdong, this paper researched the chloride ion transmission characteristics in concrete under different conditions of water cement ratio, mineral admixtures, and ion concentration and soaking, then analysed the impact on chloride ion transmission speed and comprehensive revealed chloride ion infusibility in concrete in these conditions. Through the analysis of experimental results, the complex mixtures of fly ash and silicon ash is beneficial to the durability of urban underground structure. Especially when the proportion of silicon ash is 5% and fly ash is 30%~40%, which is the most favourable to the improvement of the durability of concrete.

1. Introduction

Serious hazard caused by chloride erosion will result in huge economic losses (He et al, 2004). In 1990s the United States concrete infrastructure project cost was 6 trillion dollars, and annual maintenance cost was about 300 billion dollars, of which the railway annual maintenance cost by steel corrosion was about 20 billion dollars; By 1980 in United Kingdom, 500 thousand bridge decks need repairing due to steel corrosion; 75% of reinforced concrete bridges was corroded by chloride ion in England and Wales, and maintenance and repair costs were the 200% of the original; In Japan, about 21.4% of the reinforced concrete structure damage was caused by steel corrosion (Edgar M and Edgar V 2016; Jin et al, 2014). According to the statistics in 1998, 734 railway tunnels were corroded to crack in China, which account for 13.2% of the total number (Pilvar et al, 2015). Chengdu-Kunming Railway was seriously corroded according to the census in 1978 and some corrosion depth reached more than 30mm, so it should be paid attention that durability of tunnel structure caused by chloride corrosion (De Lemos Araújo et al., 2015; Wu et al, 2014).
According to the engineering survey of durability of typical underground structure, it has been found that the durability damage of underground structure in Guangzhou is so seriously that partial structure could not meet the requirement of normal utilization (Sim and Park, 2011). The durability damage of underground structure in this area is mainly represented by carbonation of concrete and corrosion of chloride ion and sulfation. Durability damage of underground structure in Guangzhou is accelerated by the factors of closed underground environment, high temperature and relative humidity, wetland dry cycling of underground structure and others. In the study of the influence factors of the durability of urban underground structure in Guangzhou (Kato et al, 2005). It is necessary to carry out the indoor simulation experiment on the degradation characteristics under the action of chloride ions of urban underground environment, due to the research achievement of corrosion to concrete construction of CO2 in atmosphere is more but the chloride ion is less (Chen and Chiou, 2007).

2. Experimental design of chloride corrosion

2.1 Material and ratio

The experimental material extracted by the typical underground engineering material parameters in Guangzhou on the basis of investigation adopts similar law to ratio in order to maximize the degree of similarity (Onyejekwe and Reddy, 2000). The composition of the cement was analyzed by chemical analysis before experiment and main chemical components and physical properties of experimental cement (PO42.5) ordinary silicate cement are shown in table 1 and 2.

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The main chemical components and physical properties of the experimental fly ash (I) are shown in table 3 and 4.

Table 1: Chemical Components of Experimental Cement

Chemical Composition and Mass Percentage Content /%							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	loss on ignition
P.O 42.5	24.3	4.8	3.8	55.3	4.2	2.2	2.4

Table 2: Physical Properties and Strength Indexes of Experimental Cement

Index	Density g/cm^3	Fineness		Setting time(h)		Strength (MPa)			
		80μresidue on sieve/%	Blaine specific surface area /m^2/kg	Initial setting time	Final setting time	Compressive strength		Bending strength	
						3d	28d	3d	28d
Test value	3.10	3.6	380	2.75	3.83	22.0	49.4	4.85	9.78

Table 3 Chemical Components of Fly Ash %

Sample	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
I	51.8	5.0	26.4	4.1	1.0	0.45	1.3	1.0

Table 4 Physical Properties of Fly Ash

Index	Fineness (45μm residue on Sieve) %	Moisture content %	Loss on ignition %	Density g/cm^3	Specific surface area /m^2/kg
FAI	4.0	0.20	3.5	2.30	540

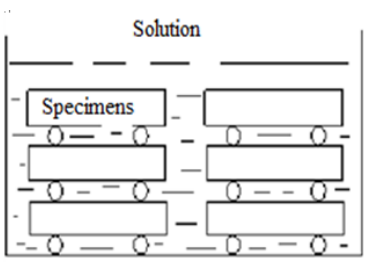


Figure 1: Schematic of soaking treatment of mortar sample

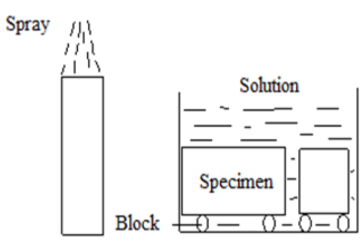


Figure 2: Schematic of spraying and soaking treatment of concrete sample

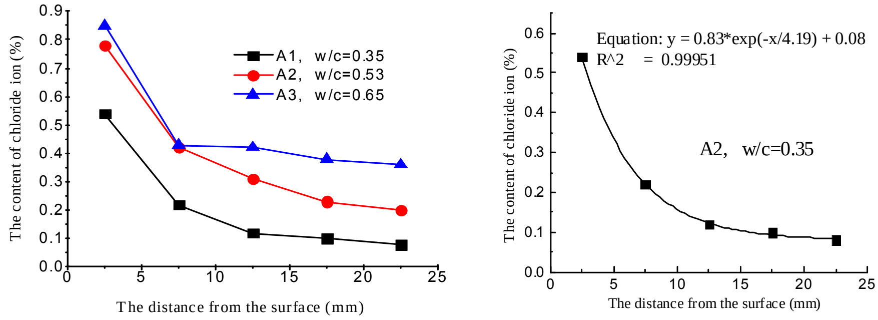
2.2 Experimental process

The ambient humidity conditions of urban underground structure were simulated by the method of spraying and soaking which respectively simulate wet and dry cycling condition and groundwater immersion condition shown in figure 1 and 2 (Vera et al, 2004). The samples for comparison were put in standard environment where the relative humidity was (50 ± 5) % and the temperature was (20 ± 3) (Yodsudjai and Otsuki, 2004). Respectively corroded 60, 90, 120 and 150 d, the samples were taken out to test the structure characteristics of Cl- content, the change of compressive strength, 6 h Coulomb electric flux and so on (Ghanem et al, 2008).

3. Results and discussion

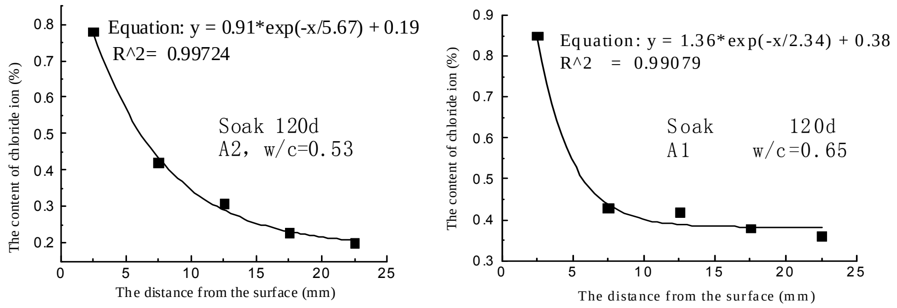
3.1 Influence of water cement ratio

Experimental data analysis indicates that the influence of water cement ratio to the diffusion of chloride ion is obvious (Tae et al., 2006). The relationship curve obtained from test between chloride ion and water cement ratio is shown in Figure 3. With the increase of the depth of the concrete surface, the content of chloride ion decreases.



(a) w/c=0.35

Figure 3: Profile curves of chlorine ion content under the influence of water cement ratio



(b) w/c=0.53 (c) w/c=0.65

Figure 4: Fitting curves of chlorine ion content under the influence of water cement ratio

From figure 1, we can see that immersed in 3.5% NaCl solution ion the content of chloride ion of samples with different water cement ratio, are changed with the increase of concrete depth. With the decrease of water cement ratio, the chlorine ion content at different depths was decreased. When the water cement ratio decreased from 0.65 to 0.53, the content of chloride ion in the distance from the concrete surface 0 ~ 10 mm did not have obviously decreased, but above 10 mm decreased obviously. For example, when water cement ratio is 0.35, the chloride ion content in the depth of 12.5mm is 0.12%.When water cement ratio is 0.53, the chloride ion content in the depth of 12.5mm is 0.31%.When water cement ratio is 0.65, the chloride ion content in the depth of 12.5mm is 0.42%. When water cement ratio was below 0.35, the content of chloride ion had obvious decrease. It is indicated that in order to increase the durability of concrete structure, we should use the concrete with relatively low water cement ratio in the underground structure, and water cement ratio influence factors analysis showed that urban underground structure durability design of water cement ratio of concrete mixture is less than 0.5.
According to the test data, the content of chloride ion in the concrete samples is fitted with the change of the depth, and the fitting curve is shown in Figure 4.
Figure 4 showed that the chlorine ion content increased with the depth which showed an attenuation relationship of natural logarithm. The experimental results showed that the water cement ratio of concrete has a great influence on the attenuation coefficient. The coefficient of independent variable x of the attenuation

function in a certain extent reflects the attenuation law and influence factors, and in the curve with low water cement ratio, x is smaller, however, in the curve with high water cement ratio, x is bigger.

3.2 Influence of mineral admixture

In order to analyze the influence of common mineral admixtures on the chloride ion diffusion, the chloride ion diffusion tests are carried out using the different admixtures but same water ratio.

According to test data, the concrete samples with 0.35 water cement ratio have been one-dimensional soaked for 120d, then their contents of chloride ion in different depth were measured, as shown in figure 5.

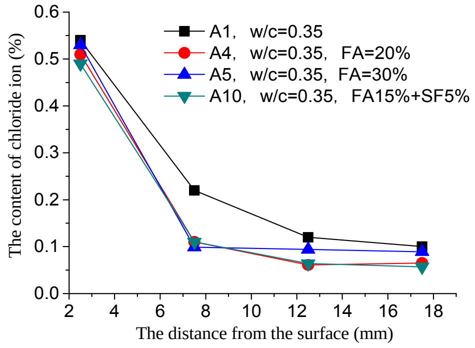


Figure 5: Profile curve of chlorine ion content under the influence of admixture

Figure 5 showed that under the same water cement ratio conditions, active mineral admixture can reduce diffusibility of chloride ion, especially in the 0~12mm depth, concentration of chloride ion obviously decreased. Among them, concentration of chloride ion of the samples with 20% or 30% fly ash and with 15% fly ash and 5% silicon ash is significantly less than the average ratio of concrete sample at different positions, especially the effect of the admixture of fly ash and silicon ash on reducing the concentration of chloride ion in surface layer (0 ~ 12mm) of concrete is obvious. The experimental results show that in urban underground structure, the use of active mineral admixture is a good measure to increase the durability of concrete structure, especially double mixed of the fly ash and silicon ash.

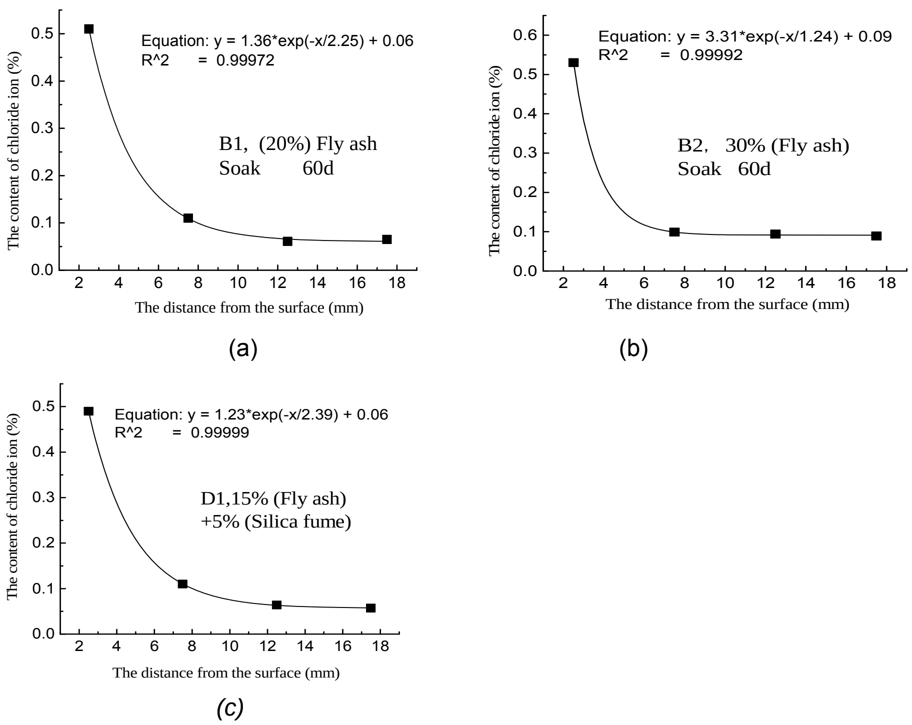


Figure 6: Profile curves of chlorine ion content under the influence of admixture

Under the influence of the admixture, chlorine ion content is fitted with change of the depth, as shown in figure 6. From figure 4 we can see, the chlorine ion content(y) with the distance from the surface (x) is also showing an attenuation relationship of natural logarithm. The attenuation coefficient of mineral admixture is greatly improved, which indicates that the mineral admixtures can effectively slow the diffusion of chloride ions. The attenuation coefficient of different samples is different, and the attenuation coefficient of fly ash and silica ash is the biggest, and the effect of slow chloride ion diffusion is the most obvious.

4. Conclusions

The conclusions can be drawn as follows:

(1) The experimental results showed that the decrease of water cement ratio can improve the permeability resistance of concrete against chlorine ion, because the water cement ratio is lower, the free water content in concrete and the porosity of concrete is decreased, and the density of concrete is improved. When the water cement ratio is reduced to 0.53, the permeability resistance of concrete against chlorine ion is improved. To improve the durability of urban underground concrete structure, concrete mix ratio requires low water cement ratio, and the proposed water cement ratio of less than 0.5 of the concrete.

(2) The experimental results showed that in urban underground structure, the use of active mineral admixture is a good measure to increase the durability of concrete structure, especially double mixed of the fly ash and silicon ash. The proper use of fly ash is beneficial to improve the durability of concrete. The incorporation of fly ash can improve the permeability resistance of concrete against chloride ion. On the one hand, due to the dense filling effect of fly ash and the effect of volcanic ash, the porosity of concrete is reduced, and the pore characteristics of concrete are also improved. On the other hand, secondary hydration reaction of calcium hydroxide crystals created by hydration reaction of fly ash and cement generates more hydration products which lead to the densification by pore refinement of cement paste. The complex admixture of fly ash and silicon ash is one of the effective ways to prepare the high resistance permeable of concrete against chlorine ion. Due to the different particle size of fly ash and silicon ash, “super-composite effect” was caused by the use of composite which lead to the complementary advantages of performance. In the durability design of urban underground structure, the content of silicon ash is determined to be 5%, and fly ash is 30%~40%.

(3)The experimental results showed that in urban underground structure, the influence of concentration of groundwater corrosion ion on the durability and service life is great; especially the alternation of dry-wet cycle accelerates the diffusion of corrosion ion, which is represented as dry-wet cycle caused by the change of underground water level, particularly detrimental to the durability of urban underground structures.

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