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Experiment Study on the Corrosion Mechanism of Mortar Anchor Solid

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With the wide application of anchored structures in various engineering, their durability and service life have become an important issue in the development of anchoring technique. The cement mortar is an important constituent of anchored structures, and the durability of the cement mortar is one of the main factors influencing anchored structures. In this paper, the method of indoor accelerated test is adopted, various unfavourable factors in the actual environment are simulated, the test data of cement mortar corrosion are obtained in a relatively short time. The research results of this thesis can provide scientific basis for the corrosion resistance of anchor cement mortar.

1. Introduction

In recent years, anchor structure has been widely used in various geotechnical engineering, but the prediction of its corrosion resistance and service life needs to be improved. Mortar is an important component of anchorage structure (Zeng et al., 2004; Zhao et al., 2006). Cement mortar plays an important role in protecting the anchor bolt, and its durability is also an important component of the durability of anchorage structures (Yan, 2005). The performance of mortar is directly related to the performance of the whole anchor structure (Chen, 2011; Zhao et al., 2005). The method of indoor accelerated test is adopted in this paper, various unfavorable factors in the actual environment are simulated, the test data of cement mortar corrosion are obtained in a relatively short time, it can provide scientific basis for the corrosion resistance of anchor cement mortar.

2. Protective effect on steel bars and carbonization of mortar

The setting and hardening of mortar is the result of hydration of cement, such as the hydrolysis reactions of tricalcium silicate:

$$2(2Cao\cdot SiO_2)+6H_2O\rightarrow Cao\cdot 2SiO_2+3H_2O+3Ca(OH)_2 \tag{1}$$

When the cement is hydrated, a large amount of calcium hydroxide is precipitated, under normal temperature, the moisture in mortar pores and capillary channels is saturated by these calcium hydroxide, pH>12.5, the remaining calcium hydroxide is deposited in the micro pores inside the mortar. A compact oxide film formed on the surface of steel bar in a strongly alkaline environment, which makes the steel bar in a passivation state (Kong et al., 2015). At the same time, mortar layer also plays a physical protective role on steel bars. However, the passivation state of the steel bar is unstable in chemical thermodynamics. Once the external conditions change, the passivation state of the steel will change to the activated state, so the corrosion will begin and continue to develop (An et al., 2016).
Cement mortar is a kind of porous body, when air or water flows through these pores, carbon dioxide dissolved in air or water react with the calcium hydroxide in mortar to form calcium carbonate, the process is called carbonization, and the formula is as follows:

$$CO_2+Ca(OH)_2\rightarrow CaCO_3+H_2O \tag{2}$$

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After the carbonization of the mortar protective layer, the alkalinity drops sharply. moreover, when hydrogen sulfide, sulphuric acid and other acid solution seep into the mortar, it will also make mortar neutral. When the mortar neutral deep into the surface of the steel bar, the PH value of the electrolyte solution near the bat surface gradually decreased to about 9, the passive film that existed on the surface of the steel bar gradually destroyed, thus creating conditions for the electrochemical corrosion of steel bar, on the other hand, the cracks in mortar provides a way for the oxygen and corrosive solution to approach the steel, which will accelerate the corrosion rate of steel (Zhang and Xu, 2010; Wang et al., 2016; Yin et al., 2017).

3. Accelerated corrosion test of cement mortar

3.1 Experimental design

(1) The selection of corrosive media
Because the solution of erosion anchorage structure usually contains Na^+, H^+, CL^-, SO_4^{2-} ions, therefore, the Na_2SO_4, HCL, H_2SO_4 are chosen as the medium to prepare corrosion solutions for corrosion tests. In order to obtain corrosion results over a long time in a relatively short time, the concentration of the medium should be improved, but the high concentration of the medium will affect the authenticity of the test results. In Na_2SO_4 solution corrosion test, the concentration of SO_4^{2-} were 1.0%, 1.5%, 3.0%. In the acid solution corrosion test, the concentration of HCL were 1.0%, 3.0%, 5.0%; the concentration of H_2SO_4 were1.0%, 3.0%, 5.0%. In order to get the relationship between the strength loss rate of cement mortar and the corrosion time, the test ages of salt solution corrosion tests were 6 months, 12 months, 18 months and 24 months; the test ages of acid solution corrosion test were 2 months, 4 months, 6 months, 8 months, 10 months and 12 months.
(2) The fabrication of Mortar specimen
The size of mortar standard is 7.07×7.07×7.07 cm^3, the strength grade of the specimen is M_5, the specimens are made of ordinary Portland cement and ordinary sand, the constituents and technical indexes of cement are shown in Table 1 and Table 2, the main technical indexes of medium sand are shown in Table 3. The mix proportion is 1:8.6:1.5 (cement, sand and water). Specimens are maintained indoors for 28 days. A group of specimens were selected as the control group, and the compressive strength was measured after curing, so as to compare with the strength of the specimens after corrosion.

Table 1: Chemical constituents of the cement (%)

Material	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
42.5R	22.02	2.65	6.19	58.99	2.53	2.67

Table 2: Technical indexes of the cement

Fineness (%)	Normal consistency (%)	Initial setting time (min)	Final setting time (min)	Compressive strength(Mpa)		Flexural strength(Mpa)	
				3d	28d	3d	28d
0.4	28.4	180	240	30.9	55.7	5.8	8.8

Table 3: Technical indexes of the medium sand

Apparent density(g/cm^3)	Bulk density (g/cm^3)		Porosity (g/cm^3)		Fineness modulus	Mud content (%)
	Loose	Close	Loose	Close		
2680	1580	1640	41.0	38.8	3.0	0.9

3.2 Test Process

(1) The cement mortar specimen is put into prepared different solution
(2) The mortar specimens soaked in solution are taken out in batches at predetermined test ages, and their compressive strength after corrosion was measured.
The mortar specimens are placed on the load pressure, and the compressive strength is measured at the loading rate of 0.5~0.75 KN per second. When the specimen is close to the damage and begins to deform rapidly, adjust the throttle of tester until the specimen is damaged, and record the failure load. To keep the specimen section uniformly pressed, lay a layer of emery or wet standard sand on the top and bottom surface of the specimen. The formula for calculating the compressive strength of mortar cubes is as follows:

$$f_{m,cu} = \frac{N_u}{A} \tag{3}$$

In the formula, $f_{m,cu}$-Mortar cube compressive strength (*Mpa*);
N_u-Mortar cube collapse pressure (*N*);
A- Specimen bearing area (mm^2).
(3) Sort out the test data

3.3 Test result and analysis

(1) Compressive strength is an important criterion to measure the quality of cement mortar. The compressive strength of specimens under test age was measured, and the strength loss rate was calculated. The test data were shown in Table 4 and Table 5.

Table 4: Strength loss rate of mortar in salt solution (%)

Corrosion medium	Concentration /%	Test age /year			
		0.5	1	1.5	2
Na_2SO_4	1.0	-3.1	-3.8	-2.9	-1.8
	1.5	-4.2	-4.4	-1.9	0.6
	3.0	-5.1	-4.3	0.5	3.2

Table 5: Strength loss rate of mortar in acid solution (%)

Corrosion medium	Concentration /%	Test age / months					
		2	4	6	8	10	12
HCL	1.0	2.6	3.5	8.1	7.6	13.6	13.4
	3.0	3.1	8.3	10.4	16.3	17.5	22.5
	5.0	4.7	12.4	14.9	22.2	23.8	32.1
H_2SO_4	1.0	3.0	3.9	9.5	9.0	15.0	13.5
	3.0	5.1	8.1	17.6	18.3	25.4	25.8
	5.0	9.1	13.0	24.1	24.6	36.2	41.4

(2) The relation between the strength loss rate and time of mortar in different concentration Na_2SO_4 solutions is shown in Figure 1. In the early stage of corrosion, the compressive strength increased, a phenomenon of “corrosion strengthening” has occurred, and there is a “period of corrosion strengthening” from strength increase to recovery to original strength. Moreover, with the increase of corrosion medium concentration, the “period of corrosion strengthening” becomes shorter. With the loss of strength accelerated, its corrosion resistance and durability decreased.
(3) At the beginning of the experiment "corrosion reinforcement" phenomenon, mainly because the SO_4^{2-}ions in the solution react with calcium hydroxide in the cement stone to form gypsum, gypsum and hydrated calcium aluminate reaction of ettringite crystal ($C_2A \cdot 3CaSO_4 \cdot 32H_2O$), the ettringite crystal contains a large amount of water, It has obvious water swelling, after expansion, the volume is about 1.5 times of the original volume, The formation of crystalline makes the mortar structure compact and solid, and the initial compressive strength is improved. But with the crystal growing, mortar internal stress increasing even exceeds the cohesion of the internal molecular cement mortar; the mortar will produce micro cracks, which leads to a decrease of the cement mortar bearing capacity.
(4) The reaction between sulfate and carbonate and hydrated calcium silicate in cement mortar produces thaumasite ($CaCO_3 \cdot CaSiO_3 \cdot CaSO_4 \cdot 15H_2O$) without cementation. With the continuous consumption of hydrated calcium silicate, the cementing material gradually becomes “argillaceous".
(5) Under the erosion of acid medium, the strength loss rate of mortar specimens is linearly related to corrosion time, as shown in Figures 2 and Figures 3. The greater the concentration of the medium, the greater the slope of the straight line in the graph, and the loss of cement mortar strength growth rate faster. Under the same concentration of medium, the corrosion damage of sulfuric acid is greater than that of hydrochloric acid.

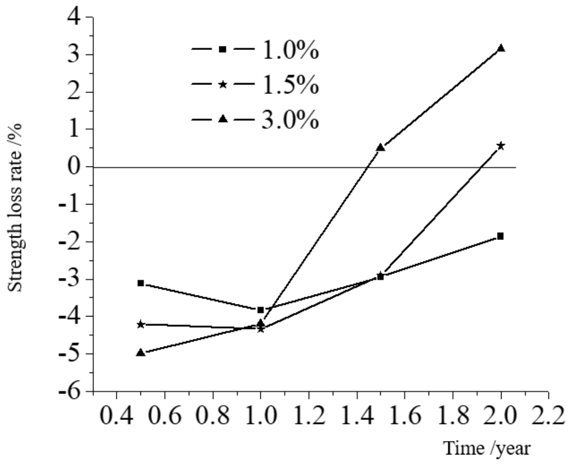

Figure 1: Strength loss rate of mortar in Na_2SO_4 solution

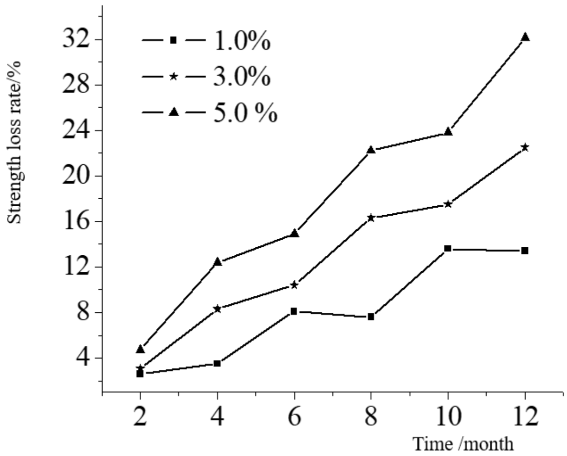

Figure 2: Strength loss rate of mortar in HCL solution

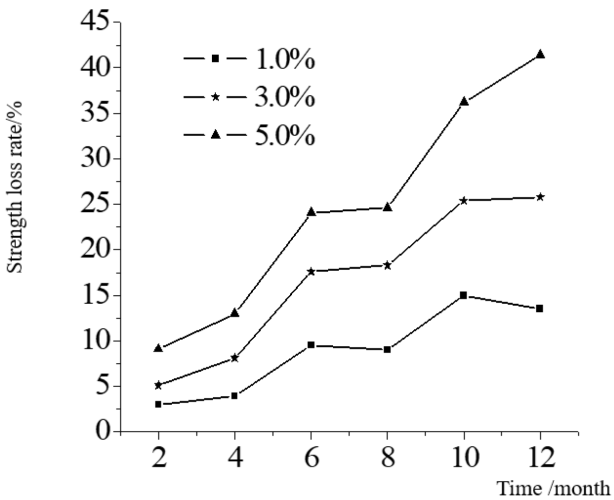

Figure 3: Strength loss rate of mortar in H_2SO_4 solution

(6) The corrosion effect of acid solution on cement mortar is obviously stronger than that of salt solution, and the corrosion of sulfuric acid solution is obviously stronger than that of hydrochloric acid solution. This is due

to the chemical reaction between the acid and some constituents of the cement stone, generated hydrate, and damage to the cement mortar layer produced from the outside to the inside. That is:

$$nCao \cdot mSiO_2 + H_2SO_4 \rightarrow Ca_2SO_4 + Si(OH)_2 \quad (4)$$

$$Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O \quad (5)$$

$$CaSO_4 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O \quad (6)$$

The reaction between hydrochloric acid and calcium hydroxide *Ca* $(OH)_2$ in cement is as follows

$$Ca(OH)_2 + 2HCL = CaCL_2 + 2H_2O \quad (7)$$

$CaCL_2$ is soluble in water and thus dissolves by water, resulting in a decrease in the strength of the mortar.

4. Conclusions

(1) Mortar is an important component of the anchor structure, and plays an important role in protecting the anchor. The quality of the mortar directly affects the performance and life of the anchor structure. When the anchor bar is wrapped well by the mortar, It is corrosion is started after the mortar has been neutralized, and the neutralization rate of mortar in corrosive environment is very slow. Therefore, the construction quality of the mortar should be strictly controlled during the construction, and the service life of the anchor structure can be improved.

(2) In the early stage of corrosion, the compressive strength of cement mortar specimens increases with the corrosion of salt medium; but with the increase of corrosion medium concentration, the loss of strength is accelerated, and the corrosion resistance is reduced. Under the erosion of acid medium, the strength loss rate of mortar specimens is linearly related to corrosion time. The medium concentration increases, the loss of strength of cement mortar growth rate faster. Under the same concentration of medium, the corrosion damage of sulfuric acid is greater than that of hydrochloric acid.

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