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Experimental study on creep property of concrete corroded by sea water

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Abstract: Creep test on concrete under simultaneous long-term compressive stress and sea water corrosion was carried out, and the effects of stress level, the type and the concentration of erosive solution on the creep property of concrete were studied. The research results show that the expansive strain of specimen immersed in sodium sulfate solution is largest and immersed in sodium chloride solution is smallest under the same small stress level. The expansive strain of specimen under compressive stress is smaller than that under no stress immersed in the same erosive solution at the same erosive time. The compressive strength of specimen is largest after immersed in sodium sulfate solution and is smallest after immersed in sodium chloride solution at the same erosive time.

Key words: Concrete; erosive solution; creep property; compressive strength

1. Introduction

The mechanical property of concrete under corrosion of sea water is an important factor for evaluating the durability of concrete structure in the marine environment, and the erosion of sea water on concrete is mainly caused by the chloride ion and the sulfate ion.

Therefore, lots of researchers investigated the mechanical property of concrete under corrosion of sea water through compressive strength test. For instance, Kumar *et al*. (1995) presented the results of an experimental study on the deterioration in the strength of concrete when subjected to sulfate attack. [1]. Park *et al*. (1999) investigated the damage of chemical attack by magnesium sulfate and sodium sulfate on normal and high strength concretes [2]. Bakharev *et a*l. (2002) performed the compressive strength test and the XRD test to investigate the durability of alkali-activated slag concrete in sulfate environment [3]. Lee *et a*l. (2005) conducted detailed experimental study on the sulfate attack of Portland cement mortars and the effectiveness of silica fume in controlling the damage arising from such attack [4]. Sotiriadis *et a*l. (2012) investigated the sulfate resistance of limestone cement concrete exposed to combined chloride and sulfate environment at low temperature [5]. Liu *et al*. (2012) carried out axial compressive strength tests for concrete columns with different strain rates to investigate the effects of sulfate attack on the dynamic strength and deformation characteristics of concrete [6]. Ramadhansyah *et al*. (2012) performed compressive strength test to evaluate the effect of RHA replacement of cement on the resistance of concrete to chloride attack with drying-wetting cycles [7]. In addition, few researchers

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investigated the variations of the tensile strength and the flexural strength of concrete attacked by sulfate ions. Boyd *et al*. (2004) used tensile strength test to investigate the effect of W/C ratio and the cement type on the resistance of concrete to sulfate attack [8]. Zhang *et al*. (2008) investigated the variation of the flexural strength of cement mortar under sulfate erosion [9].

The researchers mentioned above generally placed the concrete specimens into erosive solution for long time immersion, and the specimens were not sustained to any external force in the process of immersion, and then take the corroded specimens out for conducting compressive stength test or tensile strength test to study the evolution of compressive strength of concrete with erosing time. In fact, the experimental procedure does not consist with the actual situation. Many marine structures are often corroded by sea water under stress condition, and this phenomenon is called as stress corrosion.

So far, some scholars had carried out reseaches on the mechanical property of concrete corroded by sea water under stress condition. Piasta *et al*. (1989) studied the durability of concretes with limestone and granite aggregate under simultaneous long-term compressive stress and sulfate attack [10]. Schneider and Piasta (1991, 1992) presented the study on the behavior of concrete under Na_2SO_4 solution and sustained compressive or bending stress[11, 12]. Zivica *et al*. (1994) studied the effect of applied compressive stress on the sulfate corrosion rate of cement composites [13]. Werner *et al*. (2000) studied the stress corrosion of plain cement paste specimens under three different solution and sustained bending stress [14]. Jin *et al*. (2008), Bassuoni *et al*. (2009), Gao *et al*. (2012) and Yang *et al*. (2012) studied the damage of concrete under flexural stress and sulfate solution [15, 16, 17, 18].

Most of these researchers studied the stress corrosion of concrete under bending stress or flexural stress. Thus only the change law of flexural strength was usually attained. The compressive strength of concrete is far higher than its tensile strength, and the main function of concrete in the engineering structure is to sustain compressive stress. In addition, sodium sulfate solution was mostly used in these studies. In fact, the mechanical property of concrete will also vary under the erosion of chlorine ion. Therefore, lots of influencing factors on stress corrosion of concrete need further investigation.

In this study, the author developed testing apparatus through which the concrete specimen can be subjected to long-term compressive stress, placed the concrete specimens into sodium sulfate solution and sodium chloride solution separately, and read the deformations of specimens every five to seven days. Finally, the effects of the stress level, the type of erosive solution and the mass fraction of erosive solution on the creep property of concrete were analyzed.

2. Experimental program

2.1. Specimen preparation

The experiment used C30 grade concrete. The dimensions of the specimens were 150 mm×150 mm×300 mm. Type 32.5 Portland cement, gravel with particle size ranging from 5 to 30 mm, standard river sand and tap water were used for making the concrete specimens. The details of the concrete mixture proportions used are given in Table 1.

2.2. Testing apparatus

The author developed testing apparatus through which the concrete specimen can be subjected to long-term compressive stress. The testing apparatus is shown in Fig. 1.

One test apparatus consists of three steel plates (2 cm thickness), four high-strength rebars (30 mm diameter) and eight high-strength bolts. Gasket is placed between the bolt and the plate. A pressure sensor is placed between the first plate and the second plate, and the pressure sensor is connected to a data recorder during the time of creep test.

Three specimens were conducted for uniaxial compression tests and the pressure sensor was calibrated before creep test. Two strain gages (10 cm length) were bonded to a group of parallelly vertical planes of one specimen, and the strain gages were coated with epoxy resin and connected to the another data recorder.

The compressive stress was applied on the specimen by tightening the bolts. The deformation of the pressure sensor was read from the data recorder during the process of tightening. The testing apparatus together with the specimen were placed into the erosive solution after the compressive stress reaching the predetermined value. The deformations of specimens were recorded every five to seven days.

The bottom of the testing apparatus could not be fixed. So, the compressive stress applied on the specimen through this apparatus is relatively small, and the maximum value of stress / strength ratio is 0.1. The deformation of pressure sensor were also recorded every five to seven days. The stress level will be stabilized by tightening the bolts when the deformation reduce.

The creep tests were condcuted in the curing rome in which the temperature remained at 20°. The ersoive solutions were prepared each month. Therefore, the concentration of solution could be ensured to change unsignificantly during the testing time.

2.3. Testing procedure

(1) The uniaxial compression test before creep test

Put specimens in standard curing room for 28 days, and then take three specimens for uniaxial compression tests with strain rate of $10^{-5}S^{-1}$. The compressive strengths of specimens before corrosion were attained.

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(2) Creep test

The rest specimens were applied long-term compressive stress by using the test apparatus shown in Fig. 1, and then these specimens were placed into five kinds of solutions for erosion. They were tap water, sodium chloride solution with concentration of 3%, sodium chloride solution with concentration of 8%, sodium sulfate solution with concentration of 3%, and sodium sulfate solution with concentration of 8%. There were two specimens in each kind of solution, i.e., one specimen was under long-term compressive stress and one specimen was not. Therefore, the effects of the stress level, the type of solution and the concentration of solution on the creep property of concrete specimen could be studied through test.

The erosive solution will gradually seep into the specimen and the strain gauges will gradually be ineffective with increasing erosion time. Therefore, the time for creep test lasted only about 120 days which is not long.

(3) The uniaxial compression test after creep test

After the above creep tests, the corroded specimens were conducted for uniaxial compression test again.

3. Test results and analysis

3.1. Results of uniaxial compression tests before corrosion

The stress-strain curves of three specimens before erosion are shown in Fig.2. The uniaixal compressive strengths of the three specimens were 28.84MPa, 31.21MPa and 32.87MPa, respectively. The average compressive strength is 30.97MPa.

3.2. Results of creep tests

The strain-time curves of specimens of creep tests are shown in Fig.3.

The stress that is applied on the concrete specimen through the apparatus could not be high, thus, the maximum vaule of stress / strength ratio is 0.1. The strains of all the specimens under this stress level were expansive when immeresed in these five kinds of solutions. The creep test time for specimen immersed in sodium chloride solution with concentration of 8% under stress lasted 22 days. Therefore, the expansive strains of all the specimens when the erosion time is 22 days are compared in the following discussion.

When the erosion time is 22 days, the expansive strains of specimens immersed in sodium sulfate solutions with concentrations of 3% and 8% under no stress are 888.5×10^{-6} and 888.5×10^{-6}, the expansive strains of specimens immersed in sodium chloride solutions with concentrations of 3% and 8% under no stress are 403.5×10^{-6} and 334×10^{-6}, and the expansive strain of specimen under no stress immersed in tap water is 466×10^{-6}.

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When the erosion time is 22 days, the expansive strains of specimens immersed in sodium sulfate solutions with concentrations of 3% and 8% under stress are 505.5×10^{-6} and 506.5×10^{-6}, the expansive strains of specimens immersed in sodium chloride solutions with concentrations of 3% and 8% under stress are 341.5×10^{-6} and 330×10^{-6} and the expansive strain of specimen under stress immersed in tap water is 394.5×10^{-6}.

Therefore, the expansive strain of specimen immersed in sodium sulfate solution is largest and the expansive strain of specimen immersed in sodium chloride solution is smallest at the same stress level and erosion time.

The delayed ettringite and gypsum are formed in the specimens during the corrosion of sulfate ions and fill in the initial porosity of the specimen. Thus the strain of specimen is expansive. The hydration products will also slowly fill in the initial porosity of the specimen when immersed in tap water, and the strain of specimen is also expansive. The solubility of calcium hydroxide in concrete will be enhanced by the infiltration of chlorine ion, and this will lead to the damage of concrete. The hydration products will also appear in the specimen when immersed in the sodium chloride solution, thus, the strain of specimen is still expansive.

The expansive strain of specimen under stress is smaller than that of specimen under no stress immersed in the same kind of solution at the same erosion time.

3.3. Results of uniaxial compression tests after corrosion

The stress-strain curves of specimens after erosion are shown in Fig.4, and the values of compressive strengths are presented in Table 2.

The compressive strength of specimen after immersed in sodium sulfate solution is largest and the compressive strength of specimen after immersed in sodium chloride solution is smallest with the same stress level and erosion time. In addition, the compressive strengths of specimens after erosion are higher than those of specimens before erosion.

The strength of specimen will increase when immersed in tap water during the process of hydration products filling the initial porosity. The delayed ettringite and gypsum formed in the specimen will also lead to the increase of strength of specimen when immersed in sodium sulfate solution. Though the strength of specimen will decrease due to the enhacement of the solubility of calcium hydroxide in concrete by the infiltration of chlorine ion, the strength of specimen will also colud be increased due to the appearance of hydration products. Therefore, the strength of specimen after immersed in sodium chloride solution is higher than that with no erosion, and is smaller than that immersed in tap water.

4. Conclusions

The compressive stress applied on the specimen could not be higher under the limition of this apparatus. Therefore, the following conclusion of this study is under the condition that the compressive stress is smaller.

(1) The expansive strain of specimen immersed in sodium sulfate solution is largest and the expansive strain of specimen immersed in sodium chloride solution is smallest with the same stress level and erosion time.

(2) The expansive strain of specimen under stress is smaller than that of specimen under no stress immersed in the same kind of solution at the same erosion time.

(3) The compressive strength of specimen after immersed in sodium sulfate solution is largest and the compressive strength of specimen after immersed in sodium chloride solution is smallest with the same stress level and erosion time.

5. Acknowledgments

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Figures

Fig.1. The creep test apparatus

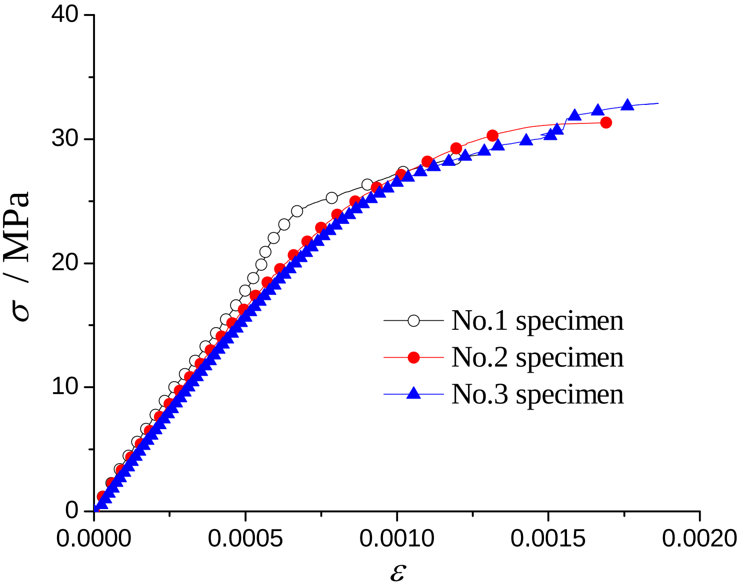

Fig.2. Stress-strain curves of specimens before immersed in solution

JCSE The Journal of Corrosion Science and Engineering
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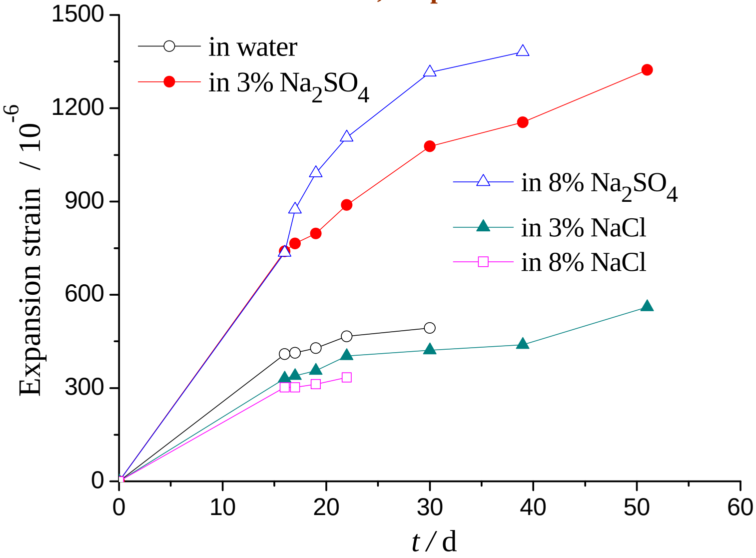
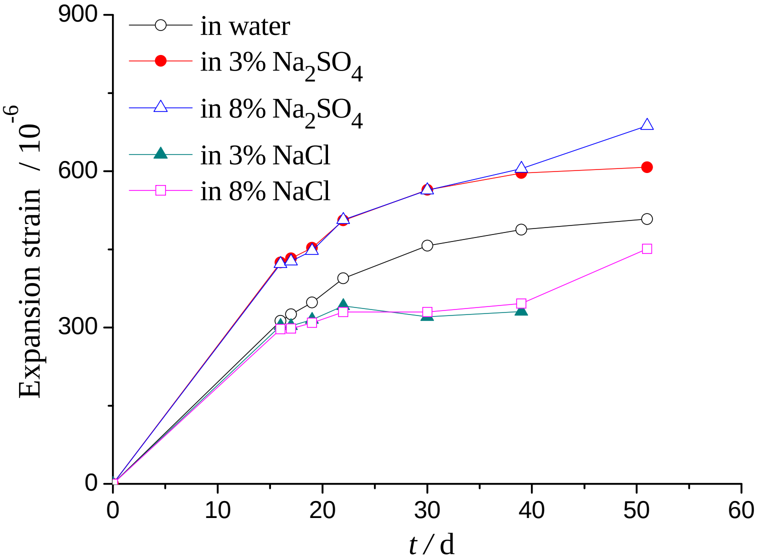


(a) Stress / Strength ratio =0.0



(b) Stress / Strength ratio =0.1

Fig.3. Expansive strains of specimens

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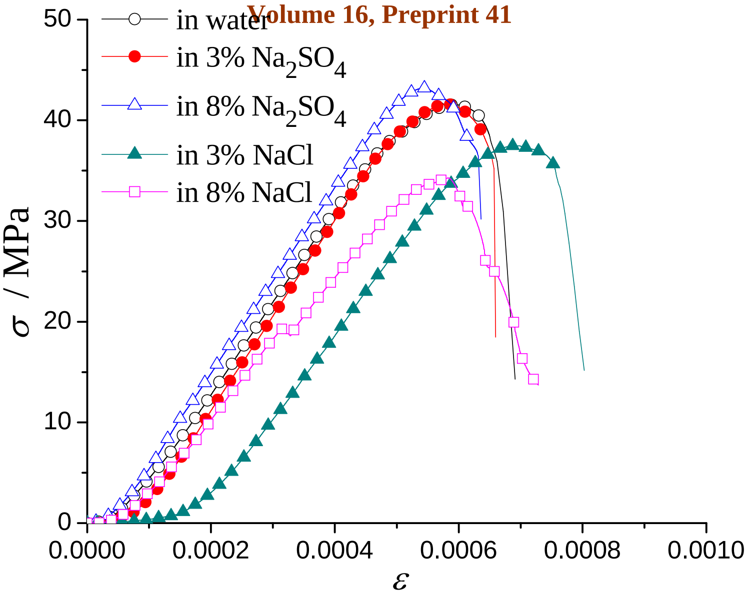
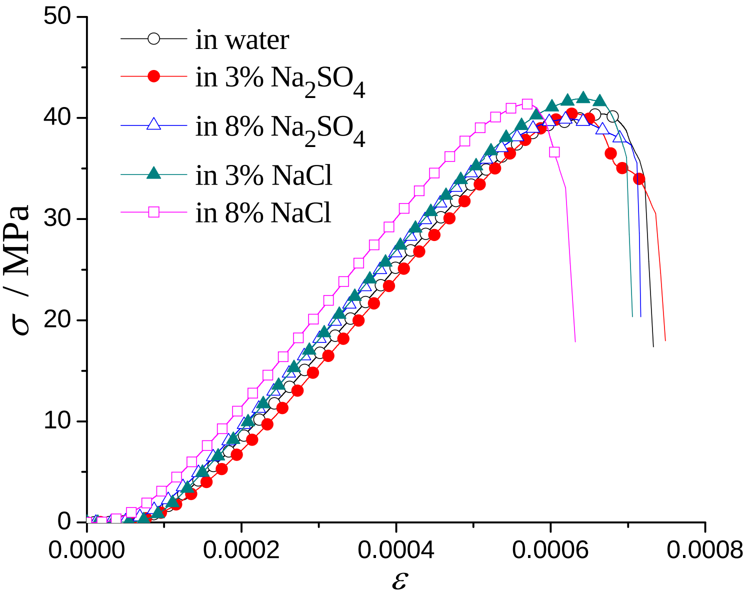


(a) Stress / Strength ratio =0.0



(b) Stress / Strength ratio =0.1

Fig.4. Stress-strain curves of specimens after immersed in chemical solutions

η_{1b}

JCSE The Journal of Corrosion Science and Engineering
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Tables

Table 1. Mixture design of concrete specimens

w/c Ratio	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)
0.45	195	433	585	1187

Table 2. Compressive strengths and peak strains of specimens after erosion

Stress / Strength Ratio	The type of solution	Compressive strength (MPa)	Peak Strain (10^{-3})
0.0	Tap water	41.54	0.593
	3% NaCl	37.47	0.689
	8% NaCl	34.26	0.583
	3% Na_2SO_4	41.59	0.581
	8% Na_2SO_4	43.21	0.543
0.1	Tap water	40.40	0.666
	3% NaCl	40.43	0.629
	8% NaCl	39.89	0.626
	3% Na_2SO_4	41.90	0.641
	8% Na_2SO_4	41.37	0.568