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SULFATE TRANSFER IN CONCRETE UNDER SUSTAINED COMPRESSIVE LOAD

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ABSTRACT

To reveal the damage characteristics of concrete under combined effects of loads and sulfate attack, some specimens with sustained compression were designed to simulate the structural concrete under service. The influences of erosion times and different compressive stresses' levels on the sulfate attack on concrete were experimental studied in this paper. The test results showed that the sulfate contents in concrete increased with the increase of time due to the damage caused by loads creep and sulfate erosion. At low compressive stress level, the concentrations of sulfate in concrete decreased with the increase of compressive stress, but it increased rapidly when the compressive stress exceeded a threshold stress level of approximate 30% of the ultimate compressive strength. In addition, the mechanisms of these changes were discussed by taking into account of the configurations of microcracks and pores in concrete under compression, and the dominant influence of the damage caused by external loads and the product of chemical reaction.

Keywords: Concrete, compression, sulfate attack, damage.

1. INTRODUCTION

Sulfate is one of the erosion media harmful to the concrete. It exists in most of costal areas and salt lake areas in China, especially the areas containing high gelling attapulgite clays, which make the structural concrete expand, craze and spall, and even lead to a destruction because of loss of strength and viscosity. It is a key factor affecting the durability of concrete, and the impact mechanism is complicated (Neville 2004, Liang and Yuan 2007, Gao et al. 2010). Recently experts have reached an agreement on the severity of sulfate attack on concrete; but the studies are mostly based on the unstressed state. According to current standards, these studies take single destructive factors, like compressive strength, flexural strength and erosion time, as evaluation indices for the durability of concrete; but there are few studies for the mechanism of sulfate's erosion and transport in concrete. We need to know the concentration and distribution law of sulfate ion in concrete to obtain the damage degree of concrete caused by sulfate ion, which is critical for the durability

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assessment of structural concrete. Moreover the destruction of concrete structure in actual environment is usually a consequence of interaction of multiple factors, such as external erosion, dry-wet process, loads, etc. Therefore, the studies of sulfate attack, which is based on unstressed state, are not in accordance with the real service state of concrete structure.

Zivica and Szabo (1994) studied the erosion property of cement mortar in sulfate solution, and found that the compressive stress improved the strength of mortar when it was below the level of 60% of the strength. Schneider et al. studied sulfate resistance of concrete subjected to compressive loading. It revealed that the compressive stress would accelerate the sulfate attack when the stress level was above 0.6 and decelerate the sulfate attack when the stress level was below 0.275 (Schneider and Piasta 1991). Work carried out by Huang Zhan et al.(2008) showed that when suffering sulfate attack the relative dynamic elastic modulus of loaded specimens degraded more greatly than that of unloaded specimens, which indicated that flexural loads accelerated the development of crack on concrete specimens and harmed the sulfate resistance of concrete. There was considerable deviation using research results of unloaded concrete to evaluate the performance of actual service structure. Therefore, to make the work more close to the engineering practice and improve the accuracy of assessment for concrete's sulfate resistance, this paper carries out an experimental study on concrete's sulfate resistance at different compressive stress levels and deeply discusses the mechanism and impact of external sustained loads on the sulfate attack on concrete.

2. EXPERIMENTAL PROGRAMME

2.1. Materials and mix proportion

The cement used for all the mixes was a P.O.42.5R ordinary Portland cement that complies with the State Bureau of Quality and Technical Supervision of China GB8076-1997. A locally available natural medium sand with a fineness modulus of 2.70 was used as fine aggregate. A locally available crushed gravel with a gradation of 5-20mm and a maximum size of 20 mm was used as coarse aggregate. Sodium sulfate was used as corrosion media, of which the molecular weight is 142.04. The mixing water was local tap water. The design compressive strength of concrete is C25. Details of the mix proportions are listed in Table 1.

Table 1 Mix proportions of concrete

Type of cement	The amount of material /(kg/m^3)				W/C ratio
	Cement	Fine aggregate	Coarse aggregate	Water	
P.O.42.5	368	619	1202	210	0.57

2.2. Design of loaded concrete specimens

The concrete prism specimens with size of 150mm×150mm×600mm were casted for the experiment. After 28 days' curing, the sustained compressive stresses were applied into concrete specimens by the system shown in Figure1. Five stress levels - $0.2f_c$, $0.3f_c$, $0.5f_c$, $0.75f_c$ and $0.8f_c$ for compressive stress, in which f_c was measured compressive strength, were subjected to the specimens. Some strain gauges were attached to the concrete surface to monitor and control the corresponding stress levels during the loading process.

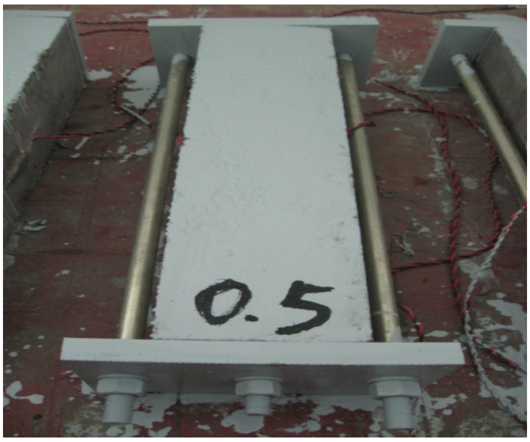

Figure 1: Specimens under sustained compressive loads

2.3. Sulfate attack determination

Different erosion environments can lead to different damage on concrete. In order to focus on evaluating the effects of SO_4^{2-} on concrete and exclude additional effects of some positive ions (like Mg^{2+}) in sulfate, Na_2SO_4 solution with a mass fraction of 10% was chose as the erosion solution. The wet-dry cycle program for this experiment was as follows. The specimens would be immersed in solution for 8 days, and then taken out and wiped, and kept dry at room temperature for 7 days. This was a cycle for 15 days. The solution should be replaced periodically to keep the concentration constant.

The erosion ages chosen for sulfate attack experiments were too short in previous studies. But it is found that the short-term concrete damage due to sulfate attack is not large, which means that the deterioration of concrete is a long-term process. Therefore the erosion ages in this paper were set as 30d, 60d, 90d, 120d, 180d, 240d, 300d, and 360d for test and analysis.

2.4. Test method

Profile grinding machine was used to take samples at each appropriate depth increment from the surface at the end of each erosion age. In order to ensure the accuracy of the test, the depth increments should be small near the surface, and beyond the depth of 7.5mm, it was chosen to be 5mm. So the sampling depths were 1mm, 3.5mm, 7.5mm, 12.5mm, 17.5mm, 22.5mm, till the maximum erosion depth (The maximum erosion depth of sulfate ion to some degree reflects the severity of concrete to sulfate attack, namely greater maximum depth indicates more serious sulfate attack). And then the barium sulfate gravimetric method was used to test the content of sulfate ion in corroded concrete. The tested initial content of sulfate ion in non-corroded concrete, Q_c, is 0.341%.

3. SULFATE IN COMPRESSIVE CONCRETE

Figures 2 and 3 show the effects of compressive stress level on the content of sulfate ions at a certain depth in concrete. It can be seen that the impact of compressive stress of $0.75f_c$ on the sulfate ion concentration is more obvious at the initial erosion age. The reason is that the compressive stress of $0.75f_c$ is a critical stress stage where the microcracks in concrete will develop unsteadily. At this stage, there are numerous and connective microcracks on the surface of concrete, which provide sufficient space for the ingression and generation of erosion products. But at the later stage of erosion, due to the chemical reactions and the block of reaction products, the concentration of ions increases gradually in concrete.

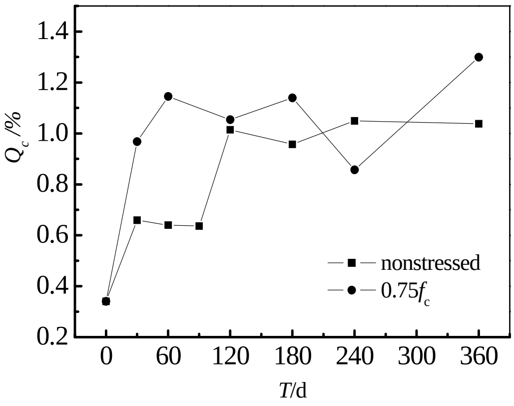

Figure 2: Sulfate contents in concrete at the depth of 3.5mm after different erosion ages

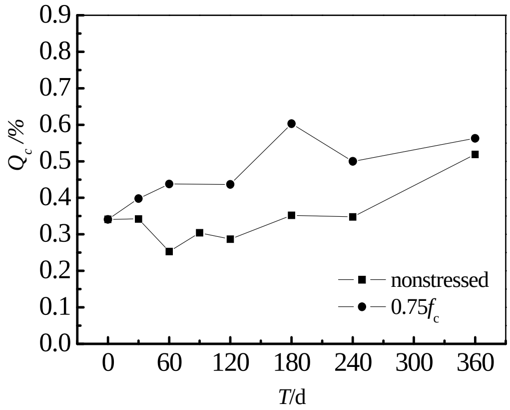

Figure 3: Sulfate contents in concrete at the depth of 12.5mm after different erosion ages

Figure 4 shows the effect of compressive stress levels on the sulfate content in concrete after 360 days’ corrosion. It is shown that at a low level of compressive stress, some microcracks, channels and even some capillary pores are closed up, which contributes to the reduction of porosity and sulfate ingression. Besides, the compressive stress will repress the expansion of erosion products, which also block the diffusion of sulfate ions in concrete. Therefore, the concentration of sulfate ions in concrete decreases at the same depth of concrete compared to the specimens without stress with the increase of compressive stress when the stress level is below $0.3f_c$. As shown in Figure 4, due to the increase of compressive stress, the concentrations of sulfate ions decrease from 1.038% to 0.701% at the depth of 3.5mm, and it decreases from 0.519% to 0.437% at the depth of 12.5mm. However, the sulfate contents increased with the further increase of compressive stress level (above $0.3f_c$). It is well known that the transportation of ions into concrete is mainly dependent upon the porosity and the connectivity of the pores in concrete. With the increase of compressive stresses, more cracks satisfying the cracking criterion will develop and coalesce, which enhances the porosity and the connectivity of pores, thus causing a increase in sulfate content. Therefore, the impact of compressive stress on the sulfate attack is depended on the stress level, and there is a threshold stress level for sulfate transportation in concrete under compression, which is approximately 30% of the ultimate compressive strength.

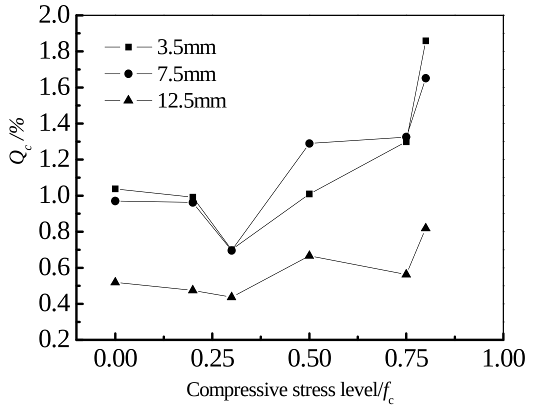

Figure 4: Effect of compressive stresses on the sulfate contents in concrete after 360 days' erosion

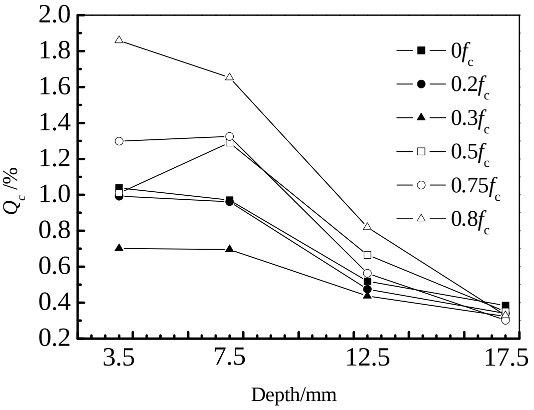

Figure 5: Sulfate profile in concrete subjected to different compressive stresses at 360 days

Figure 5 shows the profile of sulfate ions in concrete under different compressive states at the age of 360 days. At the depth around concrete surface, the erosion becomes severe with the increase of stress level and attack time, and the difference on sulfate concentration in concrete is large. As the depth increases, the filling of erosion products in concrete pores will hinder the transportation of sulfate ions in concrete, thus the difference on sulfate concentration at each layer decreases gradually under compressive stress.

4. CONCLUSION

On basis of the experimental results, the following conclusions can be drawn in this study:

(1). The distribution of sulfate ions in concrete subjected to external sustained compression depends on the interaction of stress levels and chemical reaction products. The sulfate contents in concrete increased with the increase of time due to the damage caused by loads creep and sulfate erosion.

(2). At low compressive stress level, the erosion products and the external compressive load can close some microcracks in ITZ and micropores in cement paste, which reduces the sulfate concentration in concrete.

(3). Sulfate ions in concrete increase rapidly with increase of compressive stress when it exceeded a threshold stress level of approximate 30% of the ultimate compressive strength.

5. ACKNOWLEDGEMENTS

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