Different Damaged Shaft Lining Concrete Resistance to Sulfate Corrosion

Xurong Li, Hongguang Ji*, Juanhong Liu and Shuang You

School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing, China

Abstract: Shaft lining concrete itself has a certain degree of initial damage before being corroded by sulfate. In order to study the resistance of the concrete of the initial damage in different corrosion solution concentration of sulfate, samples of concrete without initial damage, loaded 50% ultimate load and loaded 70% ultimate load with initial damage concrete were selected and studied their corrosion resistance in 9%, 12% and 15% concentrations of sulfate solution. The results show that compared with concrete with no initial damage, the concrete with initial damage resistance to sulfate corrosion is varied. With the increased concentration of the corrosion solution, the concrete with worse initial damage exhibited much lower resistance to sulfate corrosion.

Keywords: Concrete, damage, sulfate.

INTRODUCTION

Sulfate attack is one of the main factors of causing the failure of concrete, resulting in degradation of the performance of concrete structure and the service life being shortened [1, 2]. Some of the concrete structures constructed in the world have failure phenomenon because of sulfate attack [3, 4]. Therefore, some scholars have initiated the research of concrete resistance to sulfate corrosion, but the researches are for the resistance to sulfate corrosion of the concrete with no initial damage [5-8]. There are fewer studies for the performance of the concrete with initial damage under sulfate attack. However, in practical engineering, many factors will lead to concrete structure experiencing initial damage of different degree before suffering sulfate attack. Therefore, it is necessary to study the concrete with initial damage for the resistance to sulfate corrosion. This paper is based on the background of practical engineering and the main research is the ability of different initially damaged concrete for resistance to sulfate corrosion of different concentrations. It can provide theoretical basis for evaluating concrete damage in sulfate environment of practical engineering.

Linhuan Coal Mine was completed and put into operation in December 1985. It contains four shafts; main shaft, auxiliary shaft and two air shafts. The water point of auxiliary shaft is located in the main bedrock section and some water points were located at the fourth aquifer. Bedrock section of the shaft lining appears sulfate corroded by sulfate various degrees by field investigation. The concrete strength of some parts is lower than the design strength and to test by the rebound method, they need repairs. Shaft lining concrete has the initial damage because of load in the construction process. The damage of the shaft lining concrete structure in sulfate environment is more serious because of the initial damage of concrete. In order to simulate the actual working conditions, the mix proportion of the concrete used in the experiment is the mix proportion of the shaft lining concrete in actual practical environment. The concrete was damaged by the pre loading before putting it into sulfate solution. Mass change and relative dynamic modulus of elasticity express concrete resistance to sulfate corrosion in the experiment. The resistance to sulfate corrosion with no initial damage of the concrete, loaded 50% ultimate load and loaded 70% ultimate load with initial damage concrete was studied. The experimental results have certain reference significance for durability assessment and life prediction of damaged shaft lining concrete structure in the sulfate environment.

EXPERIMENTAL DESIGN

Test raw materials: P.O42.5 cement, the main performance index of the cement is shown in Table **1**. Natural sand, apparent density is 2513 kg/m^3, the bulk density is 1556 kg/m^3, the porosity is 38.1%, belongs to the second zone in the sand. Limestone, apparent density is 2761 kg/m^3, the bulk density is 1443 kg/m^3, crush index is 5%, mud content is 1.3%. C30 concrete mix sees Table **2**.

Sulfate solution of 9%, 12% and 15% concentration was mixed according to 4:1 of the mass ratio of magnesium sulfate and sodium sulfate. The specimens are 100 mm× 100 mm×100 mm cubes. Specimen grouping is shown in Table **3**. The specimens were stirred by forced action mixer and compacted by shaking table. Form removal was carried out after 24 hours. The specimens were cured in the standard curing room for 28 days. The compressive strength, ultrasonic testing and quality of the group of specimens (three specimens) is measured after curing 28 days and was taken the average. Eighty-four specimens of no initial damage specimens were put into the water with sulfate solution of 9%, 12% and 15% concentration. Eighty-four specimens were loaded 50% ultimate load and then unloaded and measured their compressive strength performed ultrasonic testing and quality, finally, they were put into the water with sulfate solution of 9%, 12% and 15% concentrations. Eighty-four specimens were loaded 70% ultimate load, and

*Address correspondence to this author at the School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing, China; Tel: 15652931549; E-mail: dr10dr10@163.com

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Table 1. Main physical property of cement.

Water demand for normal consistency (by mass)/%	Setting time/min		Fineness(by mass)/%	Compressive strength/MPa		Flexural strength/MPa	
	Initial	Final		3d	28d	3d	38d
27.8	143	214	3.0	16.2	44.5	3.8	7.1

Table 2. Mix proportion of concrete.

Concrete mark	Water-cement ratio W/C	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Stone (kg/m^3)	Nacl (kg/m^3)	$NaNO_2$ (kg/m^3)	Trolamine (kg/m^3)
C30	0.49	196	400	620	1224	4	4	0.2

Table 3. Test grouping.

Specimen grouping	Water	Specimen grouping	9% concentration	Specimen grouping	12% concentration	Specimen grouping	15% concentration
A0	No initial damage before immersing	B0	No initial damage before immersing	C0	No initial damage before immersing	D0	No initial damage before immersing
A1	Loaded 50% ultimate load before immersing	B1	Loaded 50% ultimate load before immersing	C1	Loaded 50% ultimate load before immersing	D1	Loaded 50% ultimate load before immersing
A2	Loaded 70% ultimate load before immersing	B2	Loaded 70% ultimate load before immersing	C2	Loaded 70% ultimate load before immersing	D2	Loaded 70% ultimate load before immersing

then unloading and measuring their compressive strength and performed ultrasonic testing and quality, finally, they were put into the water with sulfate solution of 9%, 12% and 15% concentrations. Three specimens of each sample were taken out from water and sulfate solution every 30 days, a total of 36 blocks. They were placed in a ventilated place to dry naturally for 24 hours and then ultrasonic testing and quality was measured and uniaxial compression test was carried out.

Relative dynamic modulus of elasticity, RDME, and mass change of concrete specimens were calculated by Eq (1) and (2).The two indexes are the basis of evaluation of concrete resistance to sulfate corrosion ability. If the relative dynamic elastic modulus reduced to 60% or the mass loss rate reached 5%, can be regarded as concrete failure.

$$M_i = \frac{m_{ni} - m_0}{m_0} \times 100\% \qquad (1)$$

Eq.(1): M_i is the mass change of specimen after soaking n months, m_{ni} is quality of specimen of the first i specimen after soaking n months; m_0 is the initial quality of specimen.

$$P_i = (\frac{v_{ni}}{v_0})^2 \times 100\% \qquad (2)$$

Eq.(2): P_i is RDME of specimen after soaking n months, v_{ni} is ultrasonic velocity of specimen of the first i specimen after soaking n months, v_0 is the ultrasonic velocity of specimen before damage.

RESULT AND DISSCUSS

As you can see from Fig. (**1**), regardless of whether the initially damaged, the relative dynamic modulus of elasticity of concrete has experienced two stages in the whole course of corrosion. The first stage is the rising period and the second stage is the declining period. The RDME without initially damaged concrete steadily rises in the water. The RDME with initially damaged concrete shows an expected downward trend after being in the corrosion solution for 120 days. While the RDME of concrete of loaded 70% ultimate load significantly decreased in water solution after 90 days. This phenomenon indicates the formation of ettringite and gypsum filling the pore of concrete and increasing the compactness of concrete material and delaying the decline in RDME. Samples left in sulfate solution of the same concentration with more initial damage has the RDME period rising more slowly and declining period decreasing more quickly. The RDME of specimens of initial damage loaded 50% ultimate load drop to below 60% when immersion period reached 180 days in sulfate solution, while the RDME of the rest of the specimens is above 60%. The RDME of specimens with no initial damage and loaded 50% ultimate load are above 60% when immersion period reached 210 days in the water while it is below 60% for the rest specimens.

From Fig. (**2**) can be seen, the mass loss rate of concrete specimens is increased in water solution. But in sulfate solution, the mass loss rate experiences three stages, the first stage is the rising period, the second stage is the period of decline, and the third stage is the rising period. The initial damage of concrete specimen is more in the same

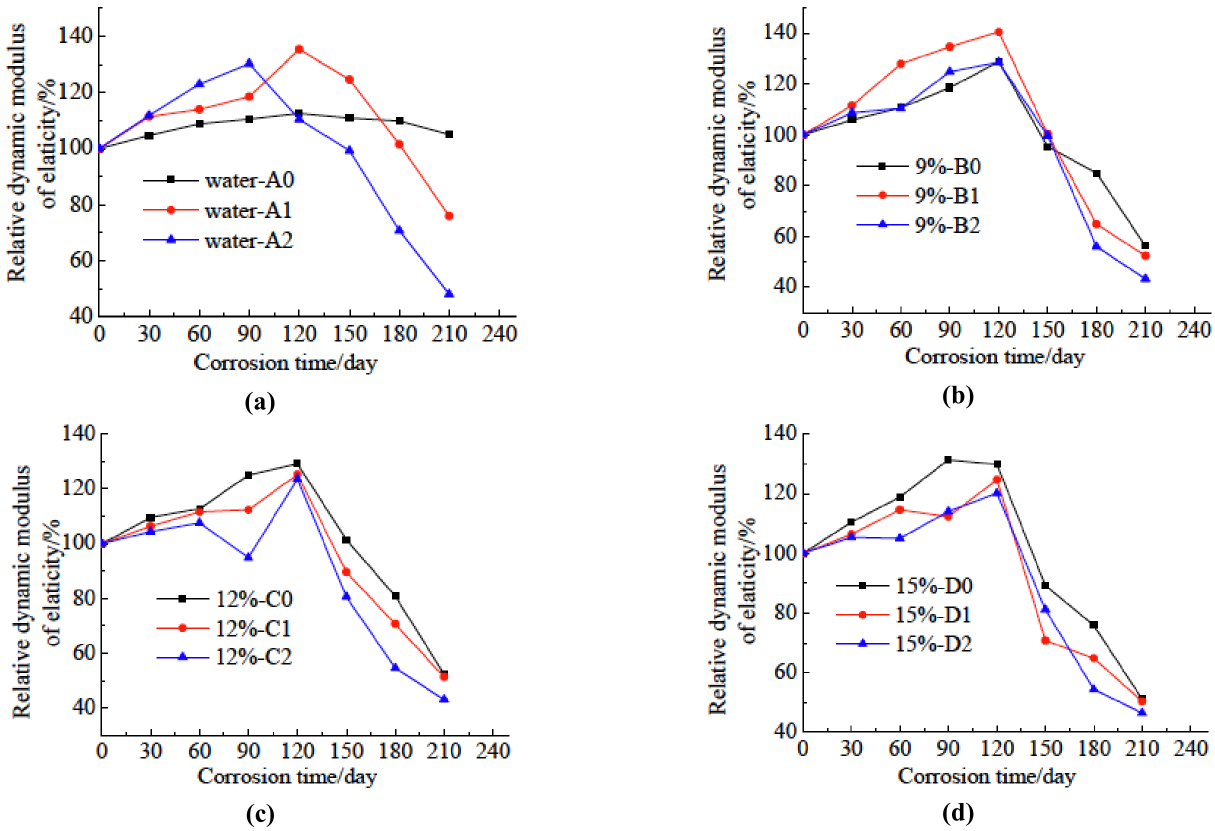


Fig. (1). Comparison of relative dynamic modulus of elasticity of different initial damage specimens in water and different concentration corrosion solution after one to seven months.

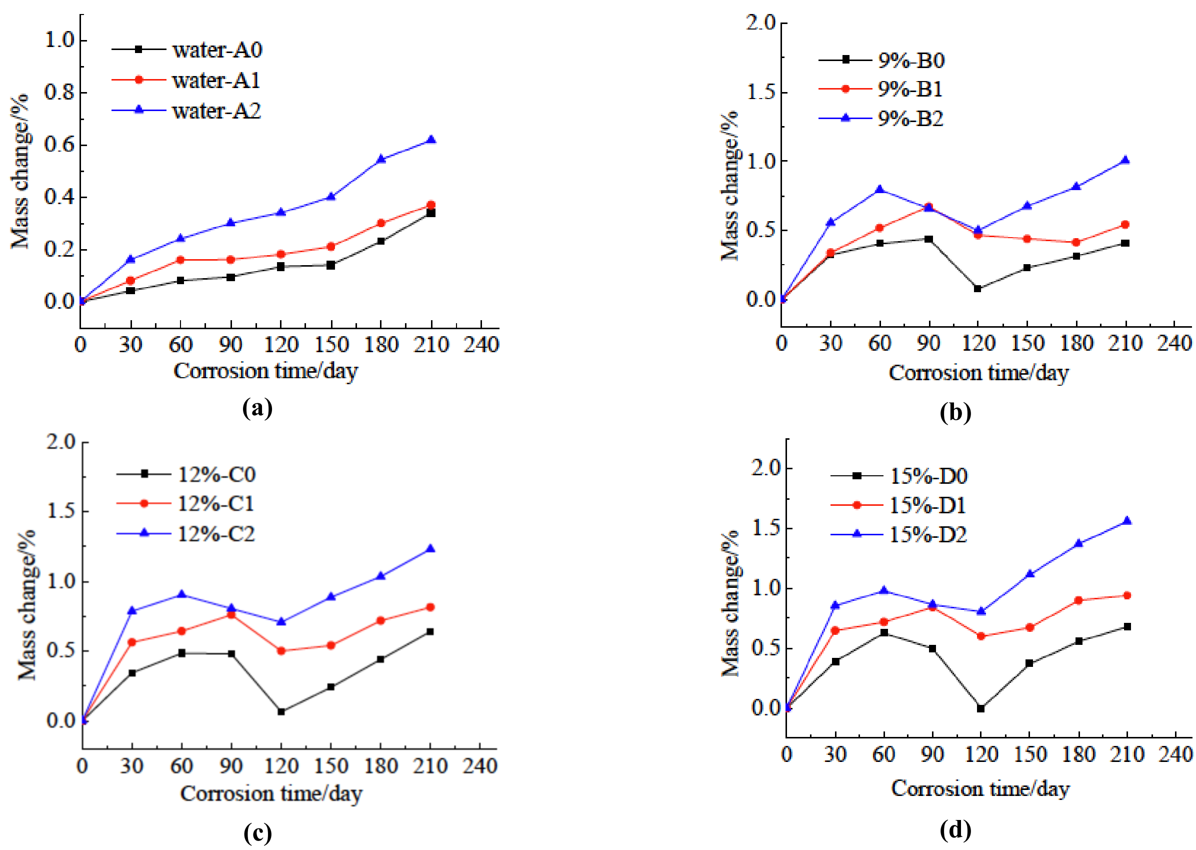
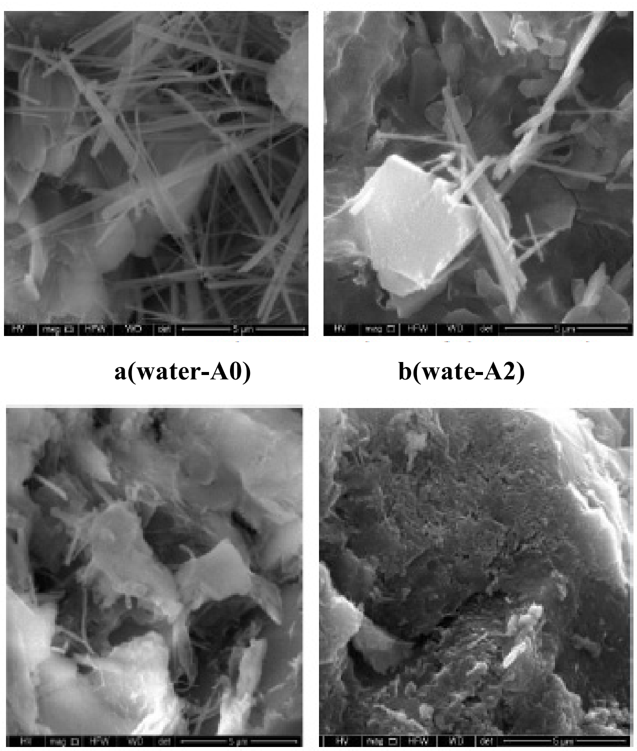


Fig. (2). Comparison of mass change of different initial damage specimens in water and different concentration corrosion solution after one to seven months.

concentration sulfate solution, quality increase more and more. The main reason of this phenomenon lies in the following stages: the first stage of concrete hydration process, calcium hydroxide etc hydration products dissolved quantity is less than the invasion of sulfate ions. The second stage, stripping amount is greater than the invasion. The third stage, with the increase of corrosion time of sulfate solution, ettringite and gypsum fills the pore. The reaction products in concrete gradually increase and the increased amount is more than the scaled mass in the concrete test, so quality of the concrete specimen increases again.

ANALYSIS OF MICRO MECHANISM

The influence of sulfate solution and the initial damage for concrete material can be obtained by a macro test. The corrosion resistance of concrete material depend on its microstructure and in order to further study the influence of sulfate solution and the initial damage to concrete material on the microstructural level a Scanning Electron Microscope, SEM, analysis is under taken. Specimens of representative were selected. They are without initial damage concrete specimens and loaded 50% ultimate load with initial damage concrete specimens in water and in sulfate solution for seven months. Selected site is fracture surface of the specimen, the surface corrosion area (far from section), and internal area (far from section). SEM results are shown in Figs. (**3**-**5**).



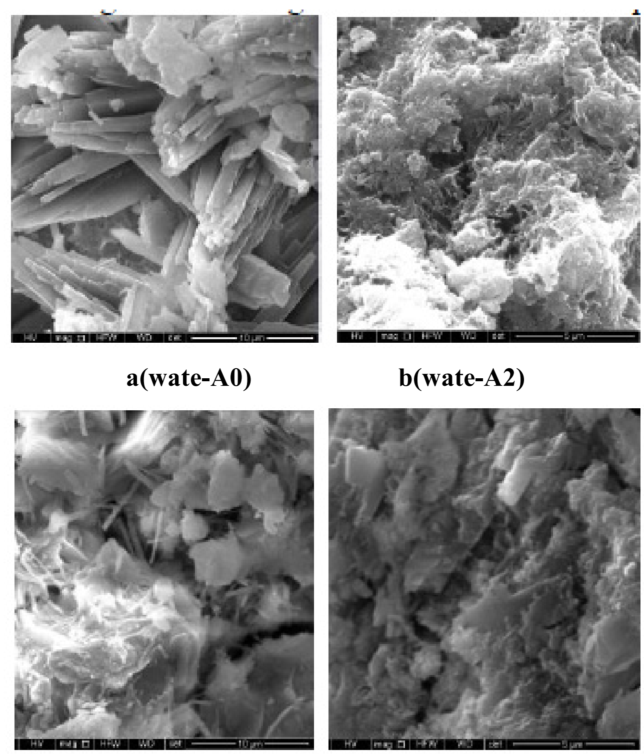
a(water-A0) **b(wate-A2)**

c(12%-C0) **d(12%-C2)**

Fig. (3). SEM image of fracture surface of specimens.

The Figs. (**3**, **4** and **5**) shows that sulfate ions infiltrates and diffuses along the long crack and pore of concrete and reach concrete relatively weak region and at the same time the hydration products of cement cause chemical reaction and produces the expanding erosion products. Erosion products first fill cracks and porosity of concrete, if the crack and pore are filled as the time goes on, erosion products of the reaction generation will produce swelling stress. If the tensile stress of expansion exceeds the tensile strength of the concrete itself, macroscopic performance will be affected and the concrete would expand, RDME and strength will be reduced. Sulfate ions enter into the concrete but the driving force is relatively small when the concentration of corrosion solution is low, so the content of sulfate ions in concrete are low, the erosion thickness is relatively small and effective bearing area is relatively large. The macroeconomic performance is slightly affected with slight deterioration of strength and the RDME is relatively large. If the initial damage is more severe, the accelerating effects of sulfate ion intrusion are more obvious in the same concentration corrosion solution. The macroeconomic performance show severe strength deterioration and the RDME decreases significantly.

Microscopic test of sections both external and internal of the specimens can provide strong evidence for the macro test data and mechanism analysis and further validates the macro test result.



a(wate-A0) **b(wate-A2)**

c(12%-C0) **d(12%-C2)**

Fig. (4). SEM image of the surface corrosion area of specimens.

CONCLUSION

(1) The resistance to sulfate attack of the initial damage concrete is worse compared to concrete without initial damage. The initial damage accelerates the process of sulfate corrosion.

(2) The resistance to sulfate attack of concrete decreases with increase of the corrosion solution concentration increases for similar concrete specimens.

(3) The resistance to sulfate attack to concrete decreases when the initial damage increases with the same concentration sulfate solution.

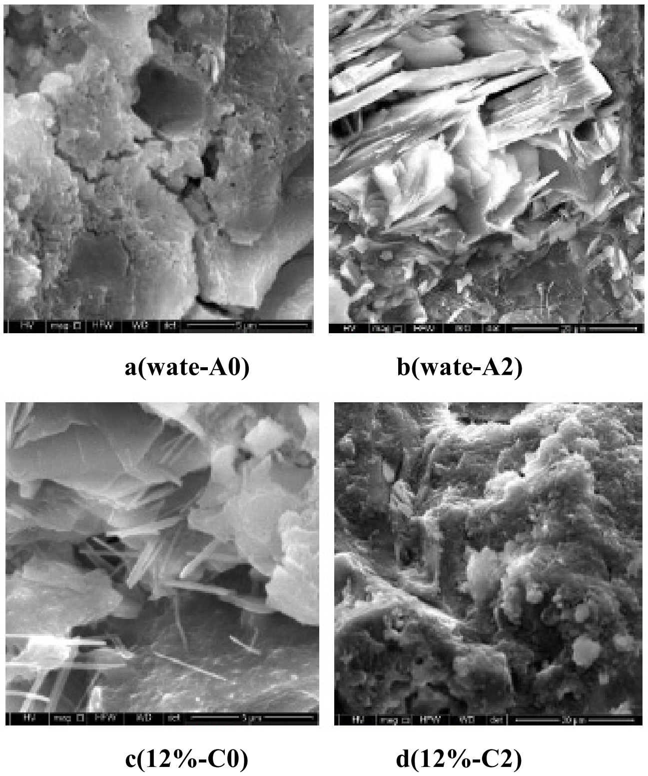


Fig. (5). SEM image of internal area of specimens.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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