



Experimental investigation on the hydraulic fracturing of cement mortar attacked by sulfate solutions with different pH values

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Abstract. Cement-based materials undergo deterioration in a sulfate environment with different pH values. This work aimed to investigate the performance of cement mortar against hydraulic fracturing exposed to sulfate environment with different pH values. For this purpose, a series of hydraulic fracturing tests and compressive strength tests on the cement mortar immersed in sulfate solutions with different pH values under different exposure periods are performed. The results showed different chemical solutions have different influences on the mechanical properties and hydraulic fracturing properties of the cement mortar specimens. After being attacked for 270 days by sodium sulfate solutions with pH values of 7 and 3, the corresponding mortar specimens exhibited critical water pressures, were 48.5% and 57.5% lower than that in their natural states, respectively. Under a sodium sulfate solution with a pH of 1, the critical water pressure of the mortar specimen decreased, the prefabricated crack on the mortar specimen was deteriorated severely after 270 days of immersion, and its resistance to hydraulic fracturing was almost lost.

Keywords: cement mortar; corrosion; pH values; hydraulic fracturing; strength; critical water pressure

1 Introduction

Cement mortar is widely used in the field of hydraulic engineering, it is often used as repair or grouting material in anti-seepage curtains, water conveyance channels, anti-seepage surfaces, and other structures^[1-3]. The corrosive media, such as sodium, magnesium, potassium, chloride, and sulfate ions, in aqueous solutions cause long-term immersion of cement mortar, involving chemical immersion and physical crystallization^[4-6]. Relevant experimental and theoretical results have been presented on this topic. For instance, Ma et al^[5] studied the deterioration behaviors of cement-based material under sulfate attack. Han et al^[7] designed four mixed solutions of

sodium sulfate and sodium bicarbonate with different pH values to study the corrosion effects of acid and alkali water environments on cement mortar.

Under the action of corrosion due to corrosive ions, the initial microcracks produced by the cement mortar develop continuously and form through cracks under the action of an external seepage pressure. The deterioration of cement mortar in complex chemical solutions and high water pressure service environment is particularly prominent, widely observed in high concrete dams, large sluices, hydraulic tunnels, and other structures^[8-10]. Therefore, it is of great significance to conduct experimental investigations on the hydraulic fracturing of cement mortar in chemical solution environments. The hydraulic fracturing damage characteristics and mechanical properties of cement mortars have been studied. For example, Chen et al^[11] conducted hydraulic fracturing tests on cement mortar using a self-made loading and water sealing device and put forward an empirical formula for the critical water pressure of the cement mortar. Zhang et al^[12] carried out hydraulic fracturing tests of cement mortar with tensile stress, and proposed a critical water pressure model based on general maximum tangential stress criterion. However, the influence of chemical solutions on the hydraulic fracturing resistance of cement mortar has not been considered in previous studies. Under the condition of a high water head, the presence of a chemical solution can easily become an important factor inducing instability and failure of the cement mortar structure. It is of great engineering value and theoretical significance to conduct tests on the mechanical properties and hydraulic fracturing characteristics of cement mortars subjected to chemical solution immersion. Hence, tests were conducted on the mechanical properties and hydraulic fracturing of cement mortars under four different chemical solution erosion conditions to analyze the evolution laws of the compressive strength, and corresponding critical water pressure during hydraulic fracturing failure in this study.

2 Experimental procedures

2.1 Specimen preparation

In order to simulate the hydraulic fracturing of cement mortar, the specimens were designed as central-notched cubes with a dimension of 150mm×150mm×150mm, and the geometry of test specimen was shown in Fig.1. The cement mortar specimens for the experiments were poured in batches. Before pouring the specimen, the inner side of the moulds and the seam steel sheets were wiped, and the release agents were smeared. The mixed mixture was injected into the test moulds and placed on a vibrating table for vibrating and compacting. After moving and resting for 3 h, the seam-forming steel sheets were loosened. Subsequently, the steel sheets were pulled out gradually after 24 h to form an initial prefabricated cut. After 48 h, the specimens were demoulded and placed into a standard curing room for 28 d.

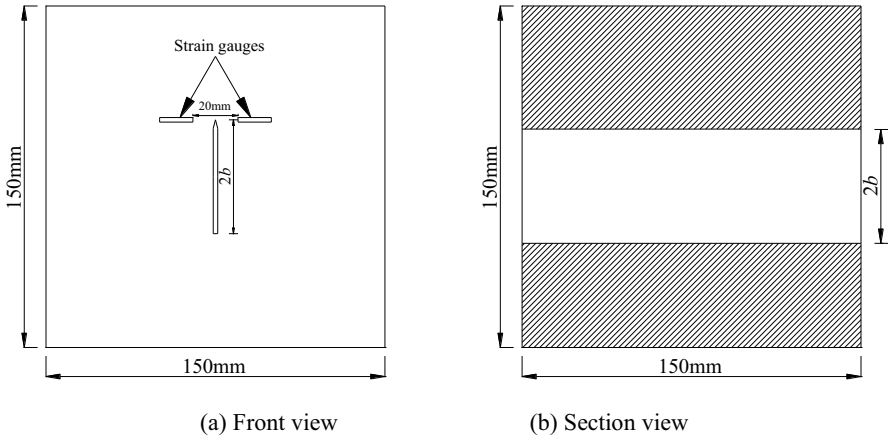


Fig. 1. Geometry of hydraulic fracturing specimen

2.2 Experimental methodology

In this study, sulfate and hydrogen ions, which are commonly observed in the field of hydraulic engineering, were mainly considered. Anhydrous sodium sulfate powder and distilled water were used to prepare the sodium sulfate solution with a concentration of 0.1 mol/L. Subsequently, a sulfuric acid reagent was titrated to prepare sodium sulfate solutions with pH values of 7 and 3 as the main test solutions. A distilled water environment was used as a blank control group, and a sodium sulfate solution with a pH of 1 was used as a strong control group.

After curing for 28 d, the specimens were removed and dried naturally. Subsequently, the dried specimens were completely immersed in the four different solutions. After 10 d, 30 d, 60 d, 90 d, 120 d, 180 d, 240 d, and 270 d, the specimens were removed and marked. The code C-0.1-3-90 in “specimen C-0.1-3-90” implies that this cement mortar specimen was eroded by a sodium sulfate solution with a concentration of 0.1 mol/L, pH value of 3, and immersion time of 90d. The compressive strength of the cement mortar specimens were tested using the universal testing machine.

3 Results and discussions

3.1 Compressive strength

Figure 2 shows the variation of the compressive strength of the cement mortar specimens under different hydro-chemical solutions. From Figure 2, the compressive strength of the cement mortar specimens immersed in the distilled water solution increased with the immersion time. After 120 d of immersion, the compressive strength of the specimen tended to be stable, which was approximately 38.7 MPa, being 25.0% greater than that at the initial moment. This can be attributed to the further hydration of

cement refined the microstructure and enhanced the compressive strength at early stage^[1].

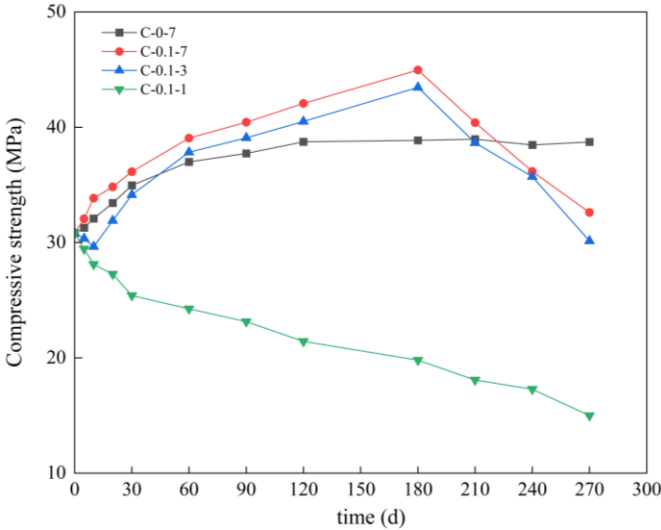


Fig. 2. Compressive strength variation of the cement mortar specimens under different hydro-chemical solutions

When subjected to the sodium sulfate solution with a pH of 7, the compressive strength of the specimen first increased and then decreased with the increase in the immersion duration. It reached the peak value of the compressive strength after 180 d of immersion, which was 40.0% greater than that at the initial time. After immersion for 180 d, the compressive strength of the specimen decreased continuously. This agreed with other research findings and can be attributed to the chemical reaction between sulfate ions and hydration products of cement^[13-14]. When subjected to a sodium sulfate solution with a pH of 3, the compressive strength of the specimen decreased within 10 d after immersion and deteriorated by 3.8% after immersion for 10 d. This was different from the strength change rule when subjected to the sodium sulfate solution with a pH of 7. As the immersion progressed, the compressive strength of the specimen gradually increased and reached its peak after 180 d of immersion, which increased by 41.0% compared with the initial moment. However, with the further increase in the immersion duration, the compressive strength decreased continuously and decreased by 30.7% after 270 d compared with that after 180 d. When the pH value of the immersion solution was 1, the degradation degree of compressive strength of the specimen is greater than that of other solution environments. The compressive strength of the specimen gradually decreases with the immersion time, after 270 d of immersion, the compressive strength of the specimen is reduced by 51.35% compared with the initial moment. This indicates that the impact of acid immersion on the compressive strength of cement mortar is greater than that of sulfate immersion.

3.2 Critical water pressure

Figure 3 shows the variation of the critical water pressure P_{IC} of the cement mortar specimen under different hydro-chemical solutions. The critical water pressure of the cement mortar specimen in natural state was 1.616 MPa. The value of the critical water pressure of the cement mortar specimen in distilled water environment gradually increased with the prolongation of immersion time from 0 to 180 days. After 180 days, the value of critical water pressure changed a little and tended to be stable at approximately 2.177 MPa, which was 34.7% greater than that at the initial time. Under the attack of the sodium sulfate solution with a pH of 7, the critical water pressure of the mortar specimens first increased and then decreased with the increase in the immersion duration, consistent with the strength evolution rule. The critical water pressure of the mortar specimens increased from 1.616 MPa to 2.701 MPa at the time of immersion for 180 d. It decreased to 0.832 MPa after immersion for 270 d, which decreased by 48.5% compared with the initial moment.

Within 20 days after being attacked by the sodium sulfate solution with a pH of 3, the variation rule of the critical water pressure of the cement mortar specimen was different from the evolution rule of the compressive strength shown in Figure 2. This was mainly because the hydrogen ions in the corrosive solution came in contact with the mortar surface. The edges and corners of the specimens were peeled off, thus reducing the adhesion between the sand particles at the edges and corners. The stress at the defects in the specimen was concentrated, and the compressive strength was reduced. The prefabricated crack of the cement mortar specimens had a small contact area with the solution and were less affected by the hydrogen ions. The critical water pressure of the specimen still increased under the hydration of the cement mortar. The critical water pressure reached the peak value of 2.515 MPa within 180 d and then gradually decreased. When the immersion lasted for 270 d, the critical water pressure decreased to 0.687 MPa, which was 57.5% lower than that at the initial time. When in the sodium sulfate solution with a pH of 1, the critical water pressure of the specimen decreased with the immersion time. After the 240-day immersion, the critical water pressure of the specimen was only 0.22 MPa, which was 86.4% lower than that at the initial moment. When the immersion lasted for 270 d, the prefabricated cracks of the specimen were seriously damaged, and the hydraulic fracturing test could not be conducted.

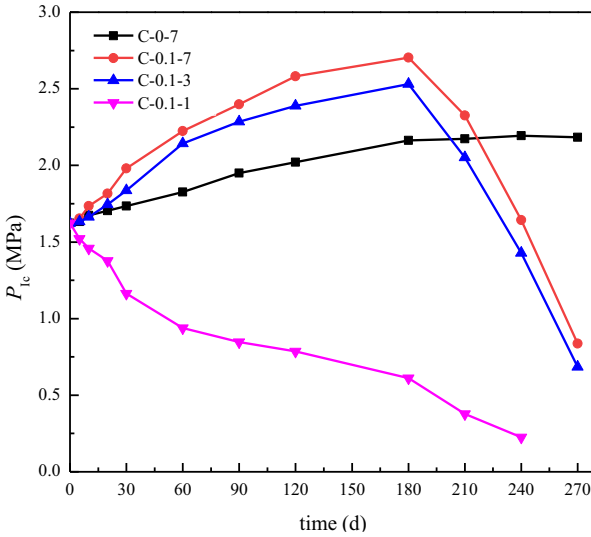


Fig. 3. Variations in the critical water pressure of cement mortar specimens under different hydro-chemical solutions

Overall, the sodium sulfate solution with a pH of 7 had a more significant effect on critical water pressure of cement mortar than distilled water. Under the same immersion time, the greater the concentration of the hydrogen ions in the sodium sulfate solutions with different pH values, the more evident the corrosion deterioration degree of critical water pressure of cement mortar.

3.3 Failure mode

Figure 4 shows the hydraulic fracturing failure morphologies of the cement mortar specimens under different immersion periods of 30 d, 90 d, and 180 d in different chemical solutions. As shown, the hydraulic fracturing failure modes of the cement mortar specimens in distilled water environment were basically consistent. The crack extends along the direction of the prefabricated crack until the specimens penetrate, and water is ejected from the splitting surface, accompanied by a dull splitting sound. The hydraulic fracturing failure morphologies of cement mortar specimens under sodium sulfate solutions with pH values of 7 and 3 before immersion for 90 days were basically consistent. The cracks extend and connect the entire specimen along the direction of the prefabricated cracks, accompanied by a dull cracking sound. At 180 days, there was no obvious macroscopic crack when the specimen was fractured by hydraulic fracturing, and water seeped from the side of the specimen. When the cement mortar specimens were immersed in sodium sulfate solution with a pH of 1 for 30 days, the hydraulic fracturing failure of the cement mortar specimen was basically carried out along the prefabricated crack, without any dull cracking sound. Immersion for 90 d, there was no significant macroscopic crack in the hydraulic fracturing failure morphology of cement mortar specimen compared to the other solutions. Meanwhile,

water seeped out from the side of the specimen. At 180 days of immersion, the water pressure in the crack of the specimen rapidly dropped to near 0 MPa, and water seeped out from the crack surface.

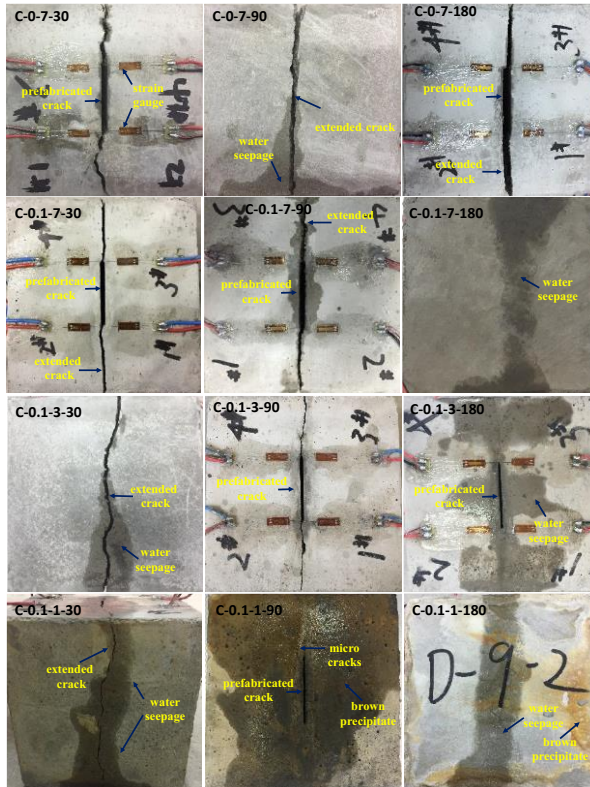


Fig. 4. Apparent morphology of cement mortar specimens with a single crack after hydraulic fracturing failure

4 Conclusions

Different chemical solutions have different influences on the mechanical properties and hydraulic fracturing properties of the cement mortar specimens. A sodium sulfate immersion solution with a pH of 7 had a more evident degradation effect on the critical water pressure of the mortar than distilled water. When subjected to sodium sulfate solutions with different pH values, the greater the concentration of the hydrogen ions in the solution, the more evident the deterioration degree of the critical water pressure of the cement mortar. After being eroded by a sodium sulfate solution with a pH of 1 for 270 days, the specimen lost its anti-hydraulic fracturing ability.

Acknowledgments

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