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Use of electrochemical method for repair of concrete cracks

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HIGHLIGHTS

- An electro-deposition test apparatus for concrete was designed.
- Four evaluation indexes of electro-deposition healing effect were proposed.
- The impact of electrolyte solution concentration on the healing effects is studied.
- The composition, morphology and developing process of deposit are analyzed.
- The difference of healing mechanisms between different electrolyte solution was found.

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ABSTRACT

With the $ZnSO_4$ and $MgSO_4$ solutions, the impact of electrolyte solution concentration on the electrodeposition healing effect was investigated, four parameters (i.e., rates of weight gain, surface coating, crack closure and crack filling depth) were measured, the mineral composition and appearance of electrodeposit in the cracks were analyzed. The results demonstrate that, regardless of how to select electrolyte solution concentration, the healing speed of cracks is the fastest during the 5 days at the beginning and the cracks basically complete healing after 20 days. In both solutions, rates of weight gain, surface coating, crack closure and crack filling depth decrease with the increase of electrolyte solution concentration. The microscopic analysis shows that the concentration of the electrolyte solution has no impact on the composition of the sediment, only affecting its morphology.

0. Introduction

Crack is the most common disease of the concrete structure, which not only affects the appearance of concrete but also reduces the strength and durability of concrete. However, the concrete cracks are almost inevitable, and its microscopic cracks are determined by its physical and mechanical properties. So the research on the concrete crack repair technique is particularly important. Electrochemical deposition repair technique is a new method to repair concrete structures disease, which has appeared internationally in recent years, repairing cracks in concrete for both the marine engineering and the land engineering. Internationally Japanese scholars Sasaki and Yokoda et al. has started studying the repair of cracks in concrete structures in a marine environment by electrodeposition method since the late 1980s [1,2]. In this study, rebar in the cracked marine concrete structure was used as cathode, and insoluble electrode was placed in the seawater as anode. After applying weak current between cathode and anode, the cations and anions move toward the two electrodes under the action of potential difference. The ions generate a series of reactions and finally form deposits on the surface and in the cracks of marine concrete structure so as to cover the concrete surface and repair the cracks. These deposits provide physical protection layer to the concrete and prevent various hazardous substances to corrode concrete in a certain degree. In accordance with this principle, researchers in Japan and the United States conducted a preliminary study on the feasibility of repairing concrete cracks on land using the electrodeposition method and the performance impact of shrinkage cracks in concrete using electrodeposition method in recent years [3–5]. The domestic research on the technology has just begun [6]. There is no report on the impact of electrolyte solution concentration on the healing effect. Therefore, the experimental study is conducted in this paper on the impact of solution concentration using the electrodeposition method to repair cracks in concrete.

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1. Experimental procedure

1.1. Raw materials

P·II 42.5 cement produced by Chinese Cement Plant is used. The physical properties and chemical composition of the cement are shown in Tables 1 and 2, respectively. Fine aggregates are the natural river sands obtained from local sources. The physical properties of river sands are shown in Table 3.

1.2. Specimen preparation

Reinforced mortar prism specimens, with dimensions of 40 mm × 40 mm × 160 mm were prepared for the following investigation. The cover depth of these specimens was 1.5 cm. The water-cement ratio of concrete specimens was 0.60 and the cement-sand ratio was 1:2.5. The diameter of the plain steel bar was 6 mm. After curing the specimens under standard conditions for 28 days, the load-induced cracks of 0.3 mm ± 0.05 mm in width on the mortar surface were made in all specimens, which were used to simulate the flexural cracks in practical engineering. Except for the cracked side, all of the other five sides of each specimen were sealed with silicone rubber. The details of specimens are shown in Fig. 1. Finally, the specimens were placed in a tank containing electrolyte solution.

1.3. Experimental procedure

Using two kinds of electrolyte solution of $ZnSO_4$ and $MgSO_4$, the comparative pilot study is made with the auxiliary electrode using flake titanium mesh, electrode distance of 40 mm, the current density controlled at 2.0 A/m^2, and the concentration of 0.05 mol/L, 0.25 mol/L and 0.50 mol/L. Each group contains three specimens and a total of 18 test specimens are used in this test. The replacement of solution is made once every 5 days so that the concentration of the solution could remain substantially constant. The test duration is 20 days. The experimental device is shown in Fig. 2, wherein the electrode distance is 40 mm, which is the distance from the center line of the steel circular side to the flake titanium mesh.

2. Evaluation index of electro-deposition healing effect

The electro-deposition speed could be reflected by the weight gain. The effect of erosion resistance of concrete with cracks that improved by the electro-deposition treatment is closely related with sediment coverage, crack closure, and the filling of cracks by sediment [5,7]. Thus, rates of weight gain, surface coating, crack closure as well as crack filling depth were used to evaluate the formation of electrodeposits in the concrete cracks.

2.1. Rate of weight gain

The specimens are taken out at an interval of 5 days. The samples are cured for 24 h at 20 ± 2 °C and 60 ± 5% RH. Then the corresponding mass was weighed. The rate of weight gain could be calculated by

$$R_m = \frac{M_i}{M} \times 100\% \quad (1)$$

where R_m is the rate of weight gain (%); M_i is the weight gain (g); M is the total weight before electro-deposition treatment (g).

Fig. 1. Details of mortar specimens before electro-deposition.

2.2. Rate of surface coating

The rate of surface coating was measured from the beginning of the test. The specimens were taken out at an interval of 5 days. The photos are taken and the rate of surface coating could be calculated by

$$R_a = \frac{A_c}{A} \times 100\% \quad (2)$$

where R_a is the rate of surface coating (%); A_c is the coated surface area (mm^2); A is the total area of the surface (mm^2).

The rate of surface coating can be calculated in the following ways such as the image segmentation methods by Photoshop or self-definition threshold during the binarization and the Ostu method with maximum variance between two classes. By comparing the segmented images with the image which was used to calculate rate of surface coating, the results were authentic. The former two methods are subjective, while the last one is dependable, automatic and quick [8].

2.3. Rate of crack closure

The rate of crack closure was measured from the beginning of the test. Eq. (3) is used to calculate the rate of crack closure of the mortar specimens.

$$R_l = \frac{L_c}{L} \times 100\% \quad (3)$$

where R_l is the rate of crack closure (%); L_c is the length of closed crack (mm); L is the total length of crack (mm).

2.4. Crack filling depth

The crack filling depth was also measured from the beginning of the test. After electro-deposition, the mortar specimens with cracks were splitted laterally along the cracks. Ten locations at equal intervals were selected to measure the filling depths with Vernier Caliper. The crack filling depth is the average value of the ten measurements.

Table 1
Physical properties of cement.

Cement type	Stability	Flexural strength (MPa)		Compressive strength (MPa)	
		3d	28d	3d	28d
P·II 42.5	Qualified	5.2	8.3	25.0	47.8

Table 2
Chemical composition of cement (wt.%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
21.52	5.13	5.25	63.86	1.46	2.28

Table 3
Physical properties of fine aggregate.

Apparent density (kg/m^3)	Bulk density (kg/m^3)	Mud content (%)	Clod content (%)	Fineness modulus	Grading zone
2620	1490	0.9	0.0	2.6	II