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The Application of a Hydrogel in the SACP System for Steel Members

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1. Introduction Sacrificial anode cathodic protection (SACP) has been pointed out as an effective method to protect steel structures from corrosion. However, the application of SACP is limited to protect steel members buried in soil or immersion environments, due to the necessity of contact with electrolytes[1]. This study proposes a new SACP system for steel members served in the atmospheric environment. In this system, an Al-based alloy plate was considered as the sacrificial anode, and a hydrogel was used as the electrolyte carrier. The ability of water absorption and retention was discussed, and electrochemical studies based on the hydrogel with different sodium chloride concentrations were performed. Furthermore, the exposure experiment was carried out to evaluate the effectiveness and durability of this system.

2. Test method The swelling ratio R_a is the criterion for describing the water absorption capacity of hydrogel. The measurement of the swelling ratio of hydrogel was conducted at 26°C by the tea-bag method. As the solutions to be absorbed, it was considered using the deionized water, and NaCl solution with different concentrations of 0.1, 3.5 and 10.0%. The weight of the wet nylon net (250 mesh) was measured and marked as W_n. The weight of the dry hydrogel material was marked as W_d. The test specimens of dry hydrogel material were suspended and fully immersed in solutions. After 48h of immersion, the tea bags were hung in the air, and then the weight of the tea bag including hydrogel was marked as W_a. After the water absorption ratio R_r measurement, the tea bags were hung in the chamber with a temperature of 30°C and humidity of 90%. And the weight, marked as W_r was measured every 24 hrs, to evaluate the water retention capacity. The R_a and R_r were calculated as follows:

$$R_a = \frac{W_a - W_d - W_n}{W_d} \qquad R_r = \frac{W_r - W_d - W_n}{W_d}$$

Moreover, electrochemical impedance spectroscopy and polarization curves were measured to investigate the electrochemical behavior of steel. The specimens were measured in the hydrogel absorbing NaCl solution of different concentrations at room temperature (26°C), while Ag/AgCl electrode in saturated potassium chloride solution was used as the reference electrode.

In addition, the durability and effectiveness of the anti-corrosion system were verified by the exposure test. The test specimens of the system include the components of the carbon steel plate (JIS G3106 SM490A) with dimensions of 150 × 70 × 9 mm, hydrogel 50× 50 × 8 mm absorbing different concentrations of NaCl aq, and alloy plate (Al-3Zn) 10 × 10× 5 mm. The galvanic current between the alloy and Fe plate was measured by a zero-resistance ammeter (ZRA), and lead wire was used to connect two types of metals to maintain short-circuit in the system during the working process.

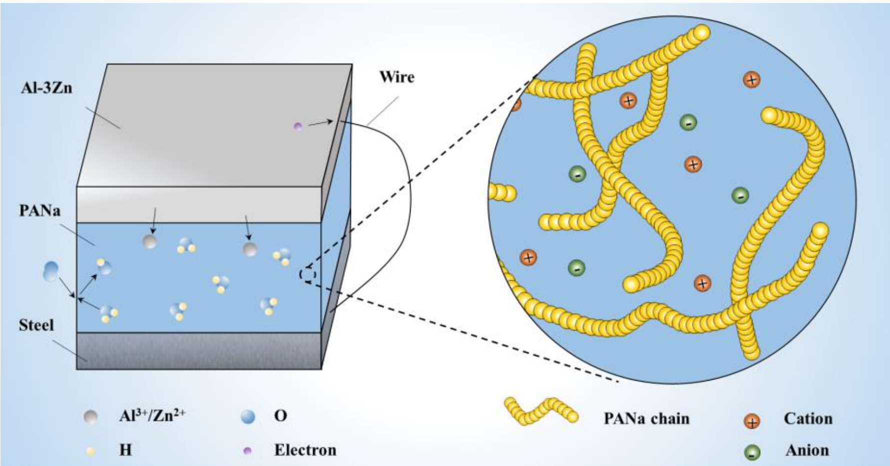

Fig. 1 . The schematic illustration of SACP method with PANa hydrogel

3. Test results The ratio of the hydrogel prepared with various concentrations of solution, is shown in Fig.1. The results indicated that the water absorption capacity of the hydrogel almost stay the same regardless of the concentrations of solution. Fig. 2 exhibits the relationship between the water retention capacity and NaCl concentration. It shows that the water retention capacity decreases with the NaCl concentration increasing, in the low concentration range. However, the hydrogel shows a remarkable water retention capacity with 10.0% NaCl aq.

The impedance diagrams for specimens immersed in the PANa hydrogels considering different concentrations of NaCl solution are presented in the Nyquist plots in Fig. 3. It illustrates that the magnitude of the impedance of the specimens immersed in the hydrogel increased sharply compared with that immersed in sodium chloride solution. Fig. 5 depicts the polarization curves of steel immersed in hydrogels with different concentrations of NaCl solution. Significantly decreased both cathodic and anodic current density was observed in specimens immersed in the hydrogel compared with that immersed in NaCl solution. An obvious trend was seen in Fig. 5 that the cathodic current density increased with the concentration of the hydrogel increasing. However, the anodic current density was not significantly altered.

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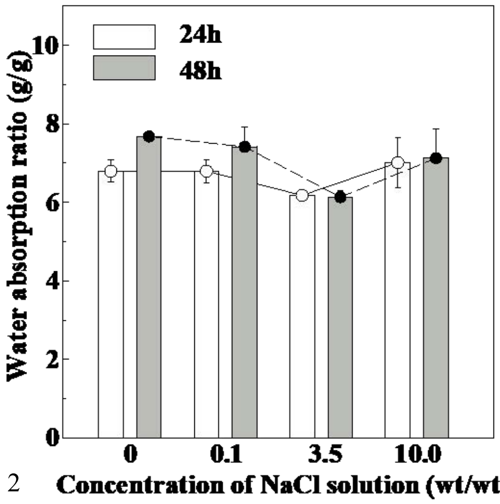

Fig. 2 Water absorption capacity.

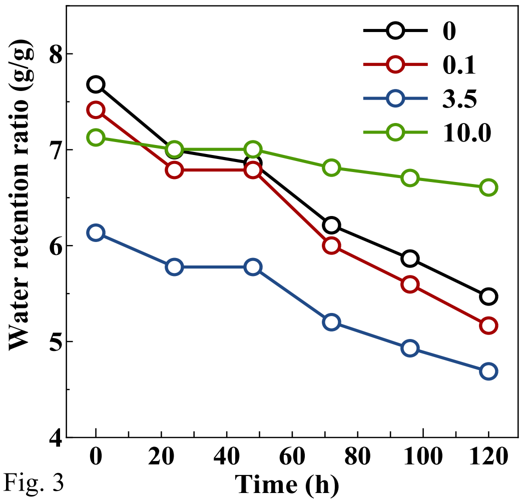

Fig. 3 Water retention capacity.

The time-dependent variations in the anti-corrosion current densities of the specimens are shown in Fig. 6. The grey line represents the protective corrosion current density, 10 μA/cm^2, which is required in seawater conditions. However, the current density required for the cathodic protection of steel in an atmospheric environment should be lower than that required in a seawater environment. Thus, the cathodic protection effect provided by the sacrificial anode metal could be expected in the atmospheric environment. The anti-corrosion current of the hydrogel with 0.1 wt% was obviously lower than that with 3.5 wt% and 10.0 wt%, and gradually decreased over time. Above all, the system with hydrogel absorbing 3.5 wt% and 10.0 wt% NaCl solution could still sustain the anti-corrosion after 200 hrs of exposure, thus ensuring its durability, based on the test results.

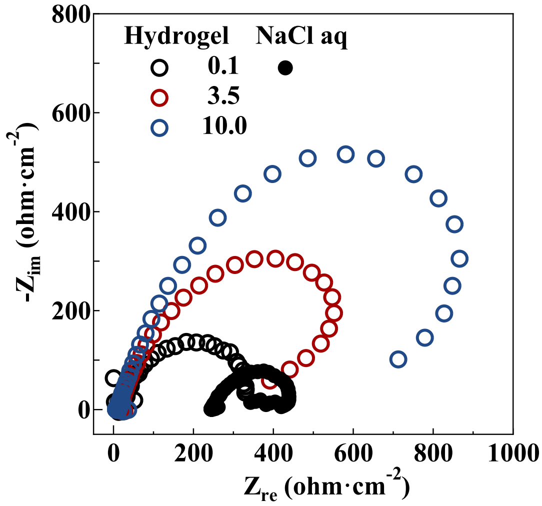

Fig. 4 Nyquist plots.

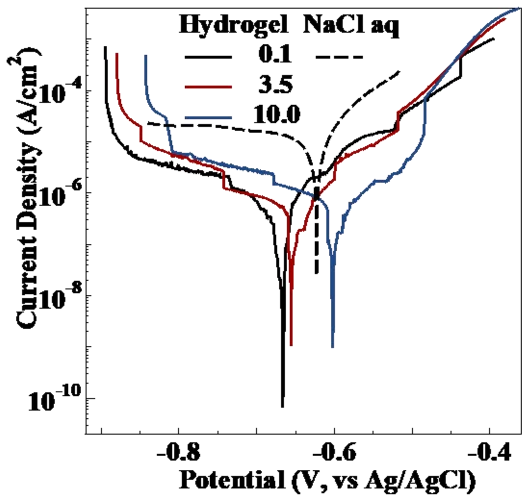

Fig. 5 Polarization curves.

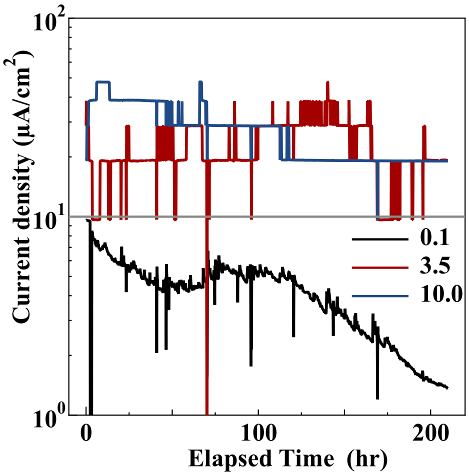

Fig. 6 Time-dependence of the anti-corrosion current density between Al-3Zn and steel plate obtained from exposure tests.

4. Summary 1) The hydrogel shows a remarkable water absorption and retention capacity with the NaCl aq, as an electrolyte carrier in the SACP system. 2) Steel immersed in the hydrogel shows great electrochemical performance, compared with NaCl solution. 3) The system can still sustain the anti-corrosion current after 200 hrs exposure, thus ensuring its durability.

References [1] Yang, M., Kainuma, S. and Ishihara, S., *Con. Bldg. Mater.* 2020, 234: 117405.

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