Sodium Polyacrylate-Sodium Carboxymethyl Cellulose Hydrogel Electrolyte of Sacrificial Anode Cathodic Protection for Carbon Steel in High-humidity Environments

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1. Introduction An ionically conductive sodium polyacrylate-sodium carboxymethyl cellulose (PANa–CMC) hydrogel electrolyte was developed for the sacrificial anode cathodic protection (SACP) of carbon steel in high-humidity environments. The incorporation of varying ratios of CMC into hydrogel formulation enhanced the water retention capacity, adhesion strength, and electrochemical performance, making it suitable for SACP applications. Particularly, PANa-5% CMC hydrogels demonstrated a current density of approximately 3 μA/cm², inhibited passive corrosion product formation, and sequestered metal ions from anodes, thus minimizing contamination. These findings highlight the substantial potential of PANa–CMC hydrogels as electrolytes, expanding the application of the SACP method to atmospheric environments.

2. Test method The PANa-CMC hydrogels were prepared via a solution polymerization method. To evaluate the water retention capacity of the hydrogels, cylinder-shaped hydrogels (diameter : 12 mm, thickness : 8 mm) were exposed to an environment with the relative humidity of 90% RH and a temperature of 30°C. Meanwhile, to determine the correlation between the quantity of CMC and adhesion properties of PANa–CMC hydrogels, dolly pull-off tests were performed between hydrogels and blast steel surface. Furthermore, EIS was used to measure the ionic conductivity of the hydrogels to evaluate the impact of the addition of CMC[1]. Two blocking stainless-steel electrodes were set in hydrogel electrolyte, as shown in Fig.1(a). A three-electrode setup was applied to evaluate the electrochemical properties of steel and Al-3Zn coupling with PANa hydrogel using a potentiostate (Princeton Applied Research, Versastat 3), as depited in Fig.1(b). In the apparatus, the steel or Al-3Zn alloy plate was performed as the working electrode, and a platinum plate and Ag/AgCl were chosen as the counter and reference electrodes, respectively. A zero-resistance ammeter was employed to measure the anti-corrosion under a constant temperature and humidity. The anti-corrosion current was monitored and recorded every 10 min. for 168 hrs.

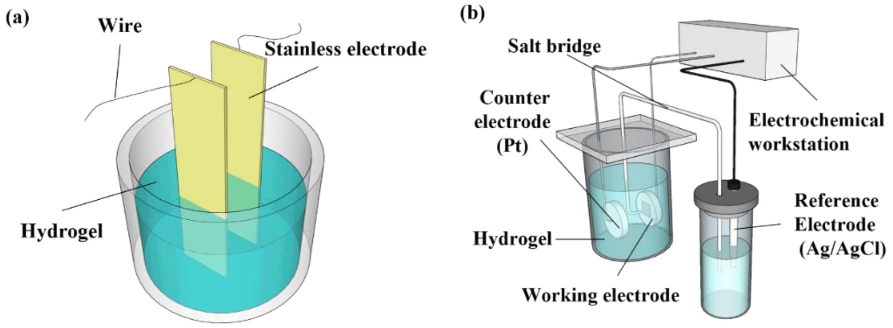

Fig. 1. Measurement method of (a) ion conductivity of PANa–CMC hydrogels, (b) electrochemical impedance spectroscopy and polarization curves.

3. Test results Fig.2(a) demonstrates the exceptional water retention capacity of PANa–CMC hydrogels, with pure PANa hydrogel losing only 2% of its water content after seven days. The addition of CMC further improved the water retention capacity, even to the point where hydrogels with 5% and 10% CMC ratios could absorb a certain amount of water from the surrounding humidity. These findings suggest that the incorporation of CMC into the PANa hydrogel can significantly enhance its water retention capabilities. Fig.2(b) reveals the influence of the ratio of CMC added in PANa–CMC hydrogels on their adhesion strength to blast steel surfaces. The results indicated that the adhesion strength increases on increasing the CMC content up to 5% and further decreases.

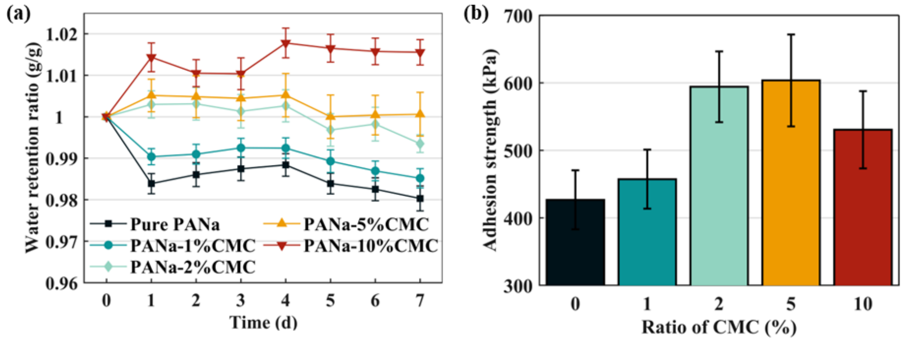

Fig. 2. (a) Water retention ratio of PANa–CMC hydrogels. (b) Adhesion strength between PANa–CMC hydrogels and blast steel.

The AC impedance tests were conducted to measure the Nyquist plot and ionic conductivity of PANa–CMC hydrogels with varying CMC ratios, as illustrated in Fig.3(a). Pure PANa hydrogel exhibited the lowest ionic conductivity of 16.1 mS/cm in comparison to the hydrogels containing CMC. As the CMC content increased, the ionic conductivity also significantly increased. Remarkably, the hydrogel with 10% CMC showed the highest ionic conductivity of 29.2 S/cm, almost double the conductivity of pure PANa hydrogel. These findings suggest that the addition of CMC can effectively enhance the ionic conductivity of the hydrogel electrolyte, thereby improving the overall performance of the SACP method.

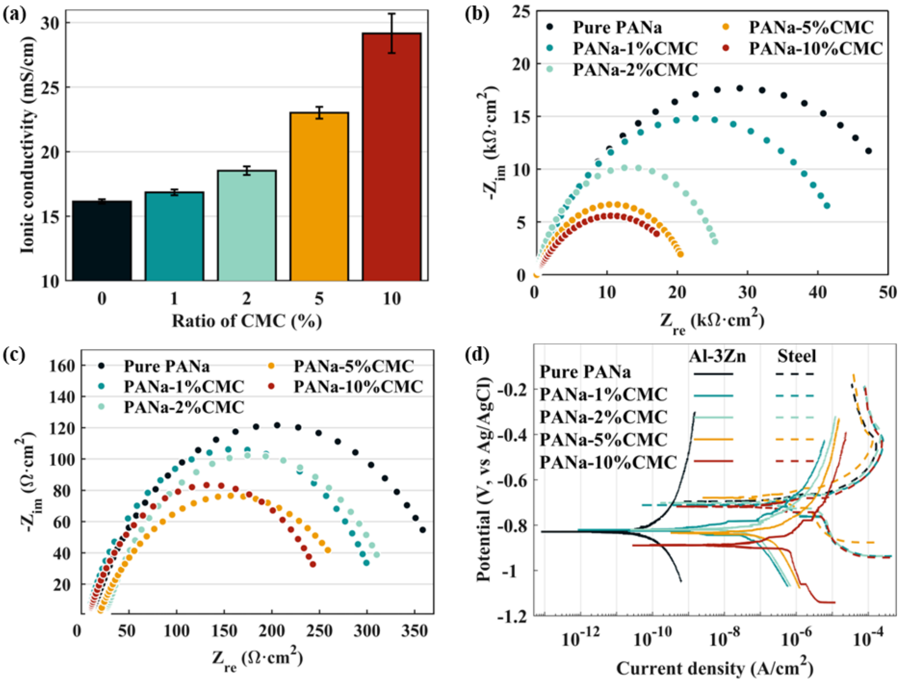

Fig.3. Ionic conductivity of PANa–CMC hydrogels considering the ratio of CMC. Nyquist plot of (b) Al–3Zn alloy and (c) blast steel immersed in PANa–CMC hydrogels. (d) Potentiodynamic polarization plot of Al–3Zn alloy and blast steel immersed in PANa–CMC hydrogels.

Fig. 4(a) presents the time-dependent changes in the anti-corrosion current density of the SACP method using PANa–CMC hydrogels. The results clearly indicate that hydrogels provide adequate protection against corrosion in high-humidity environments of 90% relative humidity.

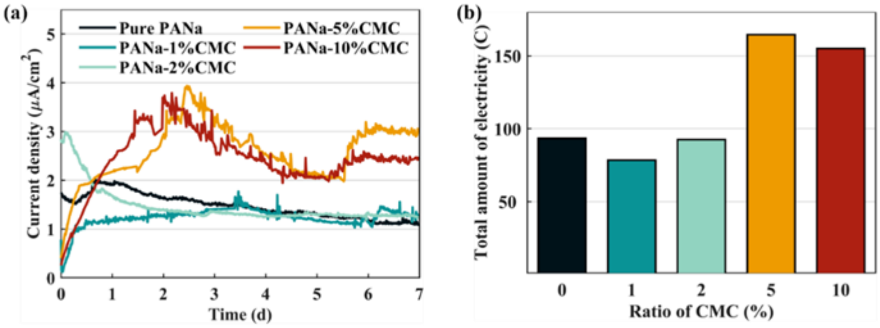

Fig.4(a) Anti-corrosion current densities provided by the SACP method using PANa–CMC hydrogels. (b) Total transferred electric charge for 7 days.

Based on the currents measured in the constant exposure test, the total electric charge can be calculated by multiplying the current by time. To assess the performance of the SACP method with PANa–CMC hydrogels, a comparison of the total electric charge over a period of seven days is presented in Fig.4(b). It was observed that when the CMC ratio is below 2%, the measured total electric charge remains relatively constant at around 90 C. However, when the CMC ratio exceeds 2%, the measured total electric charge increases sharply, approximately doubling the previous value.

4. Summary (1) The composition of CMC increases the surface roughness and introduces hydroxyl groups to hydrogels, enhancing water retention capacity. (2) The addition of CMC can enhance adhesive strength between hydrogels and steel surface. The highest adhesive strength is achieved when the CMC ratio is 5%, reaching approximately 604 kPa. (3) As the CMC content increases, the ionic conductivity of hydrogels improves and Nyquist curve radius decreases. Additionally, Al–Zn exhibits a more negative polarization potential than steel in the hydrogel. (4) PANa–CMC hydrogels coupled with Al–3Zn alloy generate and sustain a protective current to safeguard steel in high-humidity environments. Adding 5% CMC in hydrogels increases the density of the protective current up to about 3 μA/cm².

References [1] Yang, M., Kainuma, S. and Ishihara, S., *Con. Bldg. Mater*. 2020, 234: 117405. [2] Mate, C. J. and Mishra, S., *Int. Bio. Mrc*, 2020, 151: 677-690.