Temperature-Dependent Galvanic Corrosion Between Carbon Fiber and Carbon Steel

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Temperature-Dependent Galvanic Corrosion Between Carbon Fiber and Carbon Steel

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1. Introduction Carbon fiber reinforced plastic (CFRP) is commonly utilized to strengthen steel structures [1]. Despite numerous advantages of CFRP, the increasing prevalence of its application reveals gradual drawbacks. Adhesives between CFRP and steel undergo deterioration under the influence of temperature, humidity, and other environmental factors. Besides, CFRP inherently conducts electricity, and its open-circuit potential is higher than that of steel. As the adhesive deteriorates, rainwater, condensation, and airborne salt in the CFRP-reinforced area can generate an electrolyte, forming a circuit between CFRP and steel. Previous studies have demonstrated the potential for galvanic corrosion between CFRP and steels [2]. Temperature can significantly affect the galvanic corrosion rate between CFRP and carbon steel, particularly for steel bridges that that are exposed to elevated temperatures during the summer months. However, there is limited research focusing on the effect of temperature on galvanic corrosion between CFRP and carbon steel. Therefore, to examine the temperature-dependent galvanic corrosion behavior, electrochemical tests were carried out at three different temperatures (24℃, 32℃, and 40℃). Finally, a temperature-promotion factor was proposed to evaluate the corrosion rate based on the Arrhenius formula.

2. Test method **Fig.1** shows the set-up of electrochemical test. Two types of specimens were tested in this reserach. The first type was the carbon steel electrode embedded in epoxy resin and the testing area is determined by 10×10 mm (Described later as "steel electrode"). The second type was the steel electrode with carbon fiber tow (4×10 mm) pasted on the exposure side (Described later as "composite electrode"). To establish electrical contact between the carbon fiber tow and the carbon steel electrode, a conductive adhesive was employed to securely bond them. The potentiodynamic polarization (PDP) test was performed through Potentiostat. A three-electrode cell was used for PDP test. The steel electrode and composite electrode were working electrodes with a platinum wire acting as the counter electrode (CE). Besides, a commercial Ag/AgCl reference electrode (RE) saturated with KCl was adopted. The test solution was determined as 3.5 wt% NaCl aq. with reference to seawater concentration. The PDP curves were measured from -500 to +500 mV versus OCP after reaching stable state, with the potential sweep speed of 10 mV/min.

3. Test results **Fig. 2** shows the corrosion current density of steel electrode and composite electrode. The corrosion current density of steel electrodes could be determined by the polarization curve in **Fig. 2** (a). Since the PDP test for composite electrode is sensitive to noise, constant potential test was conducted for composite electrode. **Fig. 2** (b) shows the comparison of corrosion current density between steel electrode and composite electrode. The corrosion current density increased for both types of electrodes with rising temperature. Moreover, at various temperatures, the corrosion current density of the composite electrode consistently exceeded that of the steel electrode.

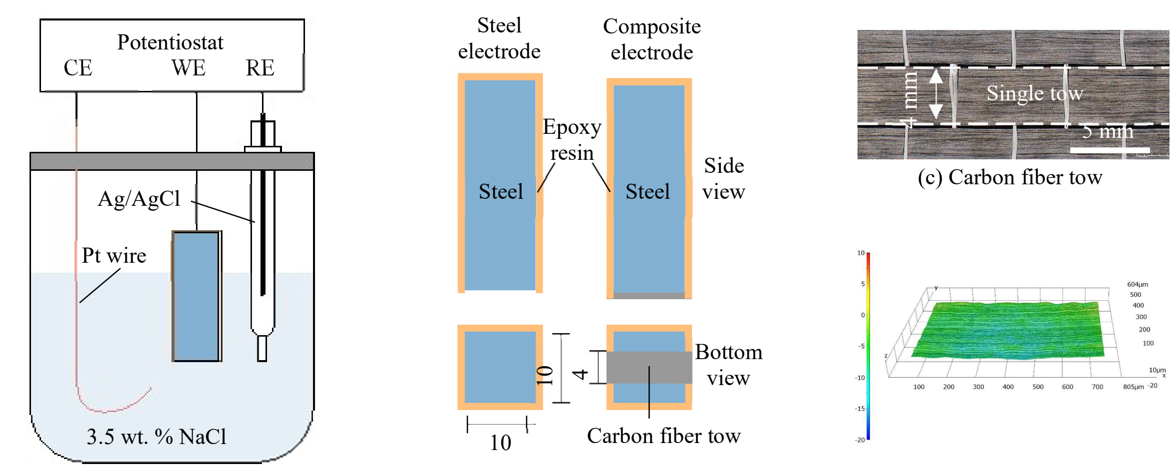
The effect of temperature on the corrosion rates of the two electrodes were discussed using the Arrhenius equation as given in Eq. (1):

$$C = Ae^{\frac{-E_a}{RT}} \tag{1}$$

where C is the reaction rate; A is the pre-exponential factor (constant for specified temperature); E_a is the activation energy; R is the gas constant. Besides, the corrosion current density can reflect the corrosion reaction rates based on Faradays' law as described in Eq.(2):

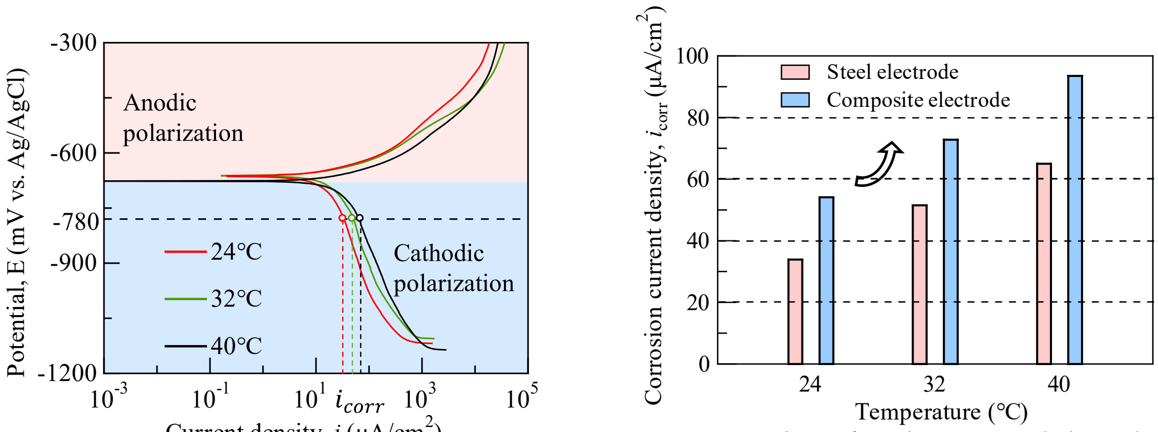
$$C = i_{corr}M/(z\rho F) \tag{2}$$

where M and F are atomic mass and Faraday constant respectively. ρ is the density of carbon steel and z is determined as 2 when Fe^{2+} is produced in the corrosion reaction.



(a) Configuration of electrochemical test (b) Configuration of specimens (d) Surface of carbon steel

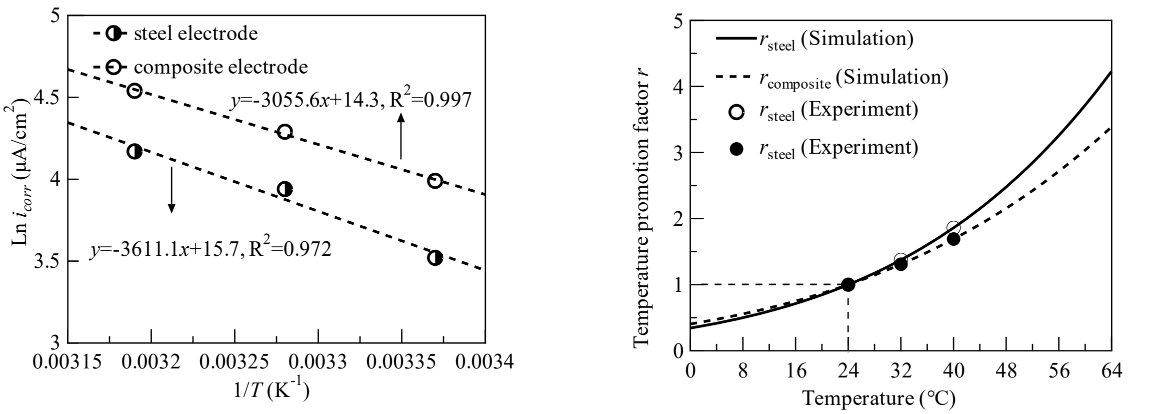
Fig.1 Configuration of electrochemical test set-up.



(a) PDP curve for steel electrodes

(b) Comparison of i_{corr} between steel electrode and composite electrode

Fig.2 Corrosion current density of steel electrode and composite electrode obtained by electrochemical test.



(a) Relationship between Ln (i_{corr}) and $1/T$.

(b) Temperature-promotion factor versus temperature.

Fig.3 Temperature promotion factor calculated through Arrhenius equation.

Thus, the relationship between the measured Ln (i_{corr}) and $1/T$ could be expressed as follows.

$$\text{Ln}\,(i_{corr}) = \frac{E_a}{R}\frac{1}{T} + \text{Ln}\left(A \cdot \frac{z\rho F}{M}\right) \tag{3}$$

The test results and fitting curves between Ln (i_{corr}) and $1/T$ are given in **Fig.3** (a). Strong linear relationship with $R^2 > 0.97$ was observed. The activation energy E_a of steel electrode and composite electrode was calculated as 30.0 kJ and 25.4 kJ respectively when R is determined as 8.31 J·K^{-1}·mol^{-1}. The energy barrier of corrosion reaction was reduced after the carbon fiber tow was pasted on the surface of steel electrode.

Taking the corrosion reaction rate of the steel electrode at room temperature of 24 °C as the base, the temperature promotion factor r under temperature T_i is defined as follows:

$$r = C(T_i)/C(24) \tag{4}$$

The relationship between the simulated corrosion promotion factor and temperature and the measured data are shown in **Fig. 3** (b). When the temperature was between 0 and 50°C, the corrosion promotion factor for the iron electrode changes from 0.34 to 2.66 relative to the temperature of 24°C, and for the composite electrode, the corrosion promotion factor changes from 0.40 to 2.29. When the temperature of the steel structure caused by the high temperature in summer rises to 50 °C, the corrosion rate of the exposed steel structure can be increased to more than two times that at room temperature.

4 Summary 1) After pasting CFRP tow, the OCP of carbon steel SM490A in 3.5 wt% NaCl will be increased, and its corrosion reaction will be accelerated. 2) Based on the Arrhenius equation, compared with the corrosion rate of the steel structure at room temperature (24°C), when the temperature of the steel structure rises to 50°C in summer, the galvanic corrosion rate will increase to 2.29 times of the former.

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